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# MIDSCALE PHYSICAL MODEL VALIDATION FOR SCOUR AT COASTAL STRUCTURES

by

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## Preface

This study was conducted by the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES). The work described herein was authorized as a part of the Civil Works Research and Development Program by the Headquarters, US Army Corps of Engineers (HQUSACE), and was performed under the *Scour at Coastal Structures* Work Unit 31715, which is in the Coastal Shore Protection and Restoration Program, CERC. Messrs. John H. Lockhart, Jr.; James E. Crews; and John G. Housley are HQUSACE Technical Monitors. Dr. Charles L. Vincent is Program Manager for the Coastal Shore Protection and Restoration Program at CERC.

This study was performed and the report prepared over the period 1 August 1988 through 30 December 1989 by Dr. Steven A. Hughes, Research Hydraulic Engineer, Wave Dynamics Division (WDD), CERC, and Dr. Jimmy E. Fowler, Research Hydraulic Engineer, Wave Processes Branch, WDD, CERC. Dr. Fowler was Principal Investigator of the *Scour at Coastal Structures* work unit during this period.

The research effort was under general administrative supervision of Dr. James R. Houston, Chief, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC. Mr. Gene Chatham, Chief, WDD, and Mr. Douglas Outlaw, Chief, Wave Processes Branch, provided direct supervision of Dr. Hughes and Dr. Fowler, respectively.

The authors gratefully acknowledge the dedicated efforts of the following personnel who helped during the laboratory phases of the study. Mr. John E. Evans, CERC, was the laboratory technician overseeing the physical model; wave data reduction was performed by Ms. Robin Hoban and Christie Sanders, CERC; installation and maintenance of instrumentation and day-to-day operation of the wave machine and data acquisition systems were performed by Messrs. David Daily, Ricky Floyd, and Lonnie Friar, Instrument Services Division, WES. The report was edited by Ms. Lee Byrne, Information Technology Laboratory, WES.

Special acknowledgment is given to Dr. Hans H. Dette, Technical University of Braunschweig, and Dr. Klemens Uliczka, University of Hannover in the Federal Republic of Germany, for making available their prototype-scale physical model results which formed the basis of comparison for the tests reported herein. Their cooperation throughout the course of the study contributed largely to the success of the research.

COL Larry B. Fulton, EN, was Commander and Director of WES during preparation of the report. Dr. Robert W. Whalin was Technical Director.



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## CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENTS

Non-SI units of measurements in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
inches	2.54	centimetres

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\*To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula:

$C = (5/9)(F - 32)$ . To obtain kelvin (K) readings, use:  $K = (5/9)(F - 32) + 273.15$ .

# MIDSCALE PHYSICAL MODEL VALIDATION FOR SCOUR AT COASTAL STRUCTURES

## PART I: INTRODUCTION

1. Scouring of noncohesive sediments in the coastal region has been a problem for engineers since the first coastal improvements were undertaken in ancient times. Modern coastal engineering recognizes the seriousness of scour at coastal structures, and measures are taken to reduce the scour potential, based largely on previous remedies that have shown some degree of success. There remains, however, a large gap between present knowledge of scour and the knowledge necessary to develop engineering tools for the prediction of scour evolution under specified environmental conditions. This gap in knowledge is not due to failure to recognize the benefits to be gained by understanding the causes of scour and developing the means for preventing it. On the contrary, much research has been directed at various aspects of the scour problem (Powell 1987). However, researchers are faced with the problem of understanding the immense complexity of the scouring mechanisms, such as waves and currents interacting with structures and resulting turbulent water motions suspending and transporting sediment away from the toe of the structure. Developing mathematical representations for this complex interaction is a formidable task indeed, and only limited progress has been made in this area.

### Physical Models

2. Physical models constructed and operated at reduced scale offer an alternative for examining coastal phenomena that are presently beyond analytical skills. Dalrymple (1985) points out two distinct advantages gained by using physical models to replicate nearshore processes: (a) the physical model integrates the appropriate equations (unknown to mortals) governing the processes without simplifying assumptions that have to be made for analytical or numerical models, and (b) the small size of the model permits easier data collection throughout the regime, whereas field data collection is much more expensive and difficult, and simultaneous field measurements are hard to achieve (Gourlay 1980). A third advantage of physical models is the degree of experimental control that allows simulation of varied environmental conditions at the convenience of the researcher.

3. Of course there are also disadvantages to using physical models, most notably:

- a. Scale effects occur in models that are smaller than the prototype if it is not possible to simulate all relevant variables in correct relationship to each other.
- b. Laboratory effects can influence the process being simulated to the extent that suitable approximation of the prototype is not possible. Typical laboratory effects arise from the inability to create realistic forcing conditions and the impact of model boundaries on the process being simulated.
- c. Sometimes all forcing functions and boundary conditions acting in nature are not included in the physical model.

Nevertheless, a capability to model accurately the processes in the nearshore zone is essential to a wide range of problems (Dean 1985), and understanding physical model laboratory and scale effects will allow researchers to utilize these models to address problems that cannot wait until a complete, or at least sufficient, mathematical description of the process is available.

4. Two types of physical models can be employed to study nearshore coastal processes, fixed-bed and movable-bed. Fixed-bed models are used to study waves, currents, or similar hydrodynamic phenomena, and the scaling effects are reasonably well understood (Dalrymple 1985; Hudson et al. 1979). Less well understood are the scaling effects inherent in movable-bed physical models intended for use in studying sedimentary problems.

## Movable-Bed Models

5. A multitude of scaling relationships for modeling coastal sedimentary processes has been proposed over the years (see Hudson et al. 1979; Kamphuis 1982; Yalin 1971; Fan and Le Méhauté 1969 for overviews and lists of references). Hudson et al. (1979) give the basic philosophy for movable-bed scale modeling as fully understanding the physical processes involved and ensuring that the relative magnitudes of all dominant processes are the same in model and prototype. They also state, "This is an impossible task for movable-bed models ..." because of the complications of the fluid-sediment interactions, and thus it is necessary to attempt to reproduce the dominant process "...with the anticipation that other forces are small." Similar views are held by Dean (1985), who lists two major requirements in proper physical modeling of sand transport processes: (a) knowledge of the character of the dominant forces and (b) an understanding of the dominant response mechanisms of the sediment.

6. In the absence of fundamental knowledge of the dominant processes and associated sediment response necessary to develop scale relationships, movable-bed scale models can be used to investigate the effects of certain parameters in systematic ways to establish general behavior patterns (Gourlay 1980).



Alternately, the researcher can abandon the idea of reproducing the dominant physical processes and instead attempt to maintain similitude of important observed engineering characteristics such as beach profile shape or longshore transport rates (Hudson et al. 1979).

7. Regardless of the approach taken to develop scaling relationships for movable-bed models, the nearly unanimous opinion among researchers is that it is important to verify the scaling laws by reproducing prototype-scale events. Preferably, the scale model should be validated using field data, but often this is not practical, and large-scale laboratory results must suffice. Only after validation can credence be given to the model results, and then only for situations which seem to be governed by the same processes that were assumed dominant in the validation. That is to say, for example, a movable-bed model validated for surf zone sediment response is not necessarily valid for application outside the surf zone because different mechanisms may be governing the transport of sediment. This leads to the axiom that scale laws should be derived with a main requirement of invariability of the scale for the material transport over the entire area of the model concerned (Bijker 1967). Under such constraints, situations where sediment is transported by significantly different mechanisms in different regions usually cannot be modeled simultaneously except at the prototype scale.

8. In spite of the problems associated with the use of movable-bed physical models, researchers must strive to improve their capabilities with these engineering tools. Dean (1985) summarizes the role of physical models by stating that they will continue to be important engineering tools for several decades because:

- a. They do not require mathematical quantification and representation of the physical processes as do numerical models.
- b. They can adequately deal with complex geometries.
- c. They offer advantages in measurement and visualization of the processes when dealing with small-scale versions of the system.

9. Bijker (1967) stated that "... a (physical) model can act as a means to guide the considerations of the engineer in charge of the design of the project"; but he also cautions, in reference to movable-bed models, "... the model is a rather dangerous tool in the hands of a not very cautious and conscientious investigator."

## Objectives and Purpose of Study

10. The objectives of the study were to determine suitable scaling relationships appropriate for modeling turbulent wave-induced scour phenomena in small-scale movable-bed physical models, to validate

the selected relationships by laboratory reproduction of a prototype-scale scour event, and to examine the relative effect of the scaling parameters on the laboratory results.

11. The purpose of the study was to arrive at a validated set of modeling criteria and constraints so that future efforts can focus on systematic laboratory investigation of scour phenomena with the goal of developing engineering tools for the prediction of scour under a variety of environmental conditions.

## Scope of Report

12. Part II of this report provides the background and reasoning supporting the selection of the scaling criteria used in this study. Part III describes the experimental facilities and the testing procedure used in the laboratory tests. Part IV presents and discusses results from regular and irregular wave verification tests. Part V summarizes results from regular wave tests in which various parameters were changed to examine the effects of these perturbations on the resulting profiles. Part VI compares profiles from the base case condition (regular waves) with the results of similar tests carried out using irregular waves. Part VII briefly examines profile results obtained after a vertical seawall was added to the base condition. Finally, the testing program and key results are summarized in Part VIII.

13. Appendices to this report give a description of the wave record analysis, present tabulated wave statistics for each experiment, provide tabulated and plotted profiles for all experiments, and present complete plotted comparisons to supplement those shown in the main text of the report.

## PART II: SCALING GUIDANCE

14. Water-related scour of noncohesive sediments in nature is caused by various environmental forces such as wave- and tide-induced currents and turbulence that act to mobilize and transport sediment grains. The interaction of the fluid with the solid boundaries of coastal structures increases the turbulence level, which is typically accompanied by increased local scour.

15. Scour can develop gradually over a long time span, such as the enlarging of a scour hole at the tip of a jetty, or rapidly during intense storms, such as at the toe of a seawall during severe wave conditions. It is reasonable to assume the dominant scour mechanisms associated with these two time scales are bed shear stress-induced sediment transport for the case of long-duration scour, and turbulence-induced sediment transport for the short-duration case. Although it is recognized that this generalization may not be strictly true, and in some situations a combination of these two mechanisms will govern, it is beneficial to have a broad framework with which to classify scour processes for the sake of developing scaling criteria.

16. This study focused on developing scaling guidance for modeling turbulence-dominated scour occurring over relatively short periods. Although the physics of this scour mechanism may be more difficult to express in terms of mathematical representations than the case of bed shear stress-related scour, favorable experience by others in the parameterization of beach erosion led to the belief that proper scaling criteria can ultimately be developed for this situation. Success in developing such a tool for studying storm-related scour has potential for great cost savings in scour prevention at coastal projects. Types of projects that could be examined with a valid movable-bed physical model include storm response of beach fills, scour at the toes of structures, and storm impacts to the fronting beach caused by seawalls.

### Movable-Bed Modeling Considerations

17. A limited number of studies have validated movable-bed modeling guidance for scour with prototype-scale data, and the observation has been made that although most guidance does well with the data used to establish the relationships, they do not fare as well with other data (Fowler and Smith 1986; Dette and Uliczka 1986; Lappo and Koshelnik 1988; Penchev, Sotkova, and Dragncheva 1986; Dean 1985). Consequently, no clear consensus presently exists regarding appropriate scaling relationships for small-scale movable-bed models of coastal scour, particularly in proximity to coastal structures. However, it can be stated that one set of universal scaling criteria covering all types and causes of coastal scour will never be developed; instead, there will be multiple sets of scaling criteria, each set specific to a particular genre of scour and the associated forcing functions, sediment characteristics, and boundary conditions. These

specific scaling relationships will make the physical model into a useful tool for studying scour, but care must be taken to assure that the entire regime being modeled behaves in a manner consistent with the assumptions of the modeling guidance. Careful thought must also be given to proper scaling of structural attributes, such as flow through rubble mounds, if scour might be influenced by such interactions.

## Scaling Requirements

18. Many investigators have expressed opinions regarding the important physical parameters and scaling requirements to be considered in formulating guidance for movable-bed models of coastal sedimentary processes. Rather than exhaustively reviewing the literature, only those parameters or requirements that appear to be predominant (to the authors) will be discussed.

19. Important sediment-related parameters are the mean (or median) grain size, immersed weight of the bed material, the sediment fall speed (settling speed of the grain's centroid), and the Shield's parameter (indicator of the fluid velocity necessary to initiate sediment movement). Additional modeling parameters are wave height, wave period, water depth, initial bottom configuration, and process duration.

20. The most common scaling problem arises when the prototype grain size is so small that geometric scaling of the sediment results in model bed material below the size considered the boundary between cohesive and noncohesive sediment (about 0.08 mm), thus altering the sediment transport mechanism in the physical model. Some researchers have developed dimensionless parameters by combining several of the sediment parameters listed above. Then, instead of decreasing grain size, similarity of the dimensionless parameter is maintained by using a bed material having, for example, a smaller specific weight than the bed material in the prototype. Unfortunately, lightweight materials introduce another set of problems, so that many investigators now recommend that the same type of sediment in the prototype be used in the model.

21. Distortion of the scale model, i.e., different vertical and horizontal length scales, has also been suggested as a means for overcoming the inability to geometrically reduce the sediment to model scale, and many scaling laws have been proposed that require model distortion; but this practice is still viewed with skepticism by some. Dean (1985) reviewed several studies and concluded that the state of knowledge on movable-bed models was largely based on empirical observations. Further, he argued against the use of dissimilar bed materials in scale models and also against distorting the model as required by many scaling relationships. This guidance essentially constrains the coastal processes movable-bed physical model to being geometrically undistorted using (most likely) fine-grained sand as the model sediment.

22. Perhaps the most relevant requirement for modeling coastal scour, as well as nearshore beach dynamics, is to attain similarity of the equilibrium beach profile between prototype and model, particularly in the surf zone. Parameters that appear to correspond to features of the equilibrium profile are similarity candidates for developing scaling criteria.

23. For physically modeling sediment transport processes predominantly driven by turbulence-induced fluid velocities, there is increasing evidence that a dimensionless number, commonly referred to as the fall velocity (or fall time) parameter, must to be kept similar in both prototype and model. This evidence is reviewed below.

### Dimensionless Fall Speed Parameter

24. Sediment grain size has often appeared in various dimensionless parameters intended for use in characterizing observed features of the beach profile. For example, Iwagaki and Noda (1963) investigated laboratory-formed beach profiles using the parameter  $H_o/d^1$ , where  $H_o$  is the deepwater wave height and  $d$  is the sediment mean grain size diameter.

25. More recently, increased attention has been given to a parameter referred to as the **fall velocity parameter**, which is defined as

$$\frac{H}{wT} \quad (1)$$

where

$H$  = wave height

$w$  = fall speed of the median sediment size

$T$  = wave period

26. Strictly, the term *velocity* represents a vector quantity and should be replaced with *speed* because the value of  $w$  is obtained as the fall distance divided by the fall time and hence represents an average scalar speed in the vertical direction.<sup>2</sup> For this reason the parameter given by Equation 1 will be referred to as the **fall speed parameter** in this report.

27. It appears that the use of the fall speed parameter was first proposed by Gourlay,<sup>3</sup> who suggested using the parameter for describing beach processes. Gourlay pointed out that  $H/w$  represented "... the time taken for a sand particle to fall a distance equal to the wave height." If this time is large compared with the wave period, he reasoned the particle would remain in suspension and move as suspended load. Conversely, if the time is equal to or less than the wave period, then the sediment will move primarily as bed load. Gourlay also suggested that a fall speed parameter value around unity could be critical value in determining the different transport mechanisms leading to different profile types.

28. Around the same time, several other investigators also examined their results in terms of the dimensionless speed parameter. Nayak (1970, 1971) related beach slope with the parameter, and he noted

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<sup>1</sup> For convenience, symbols and abbreviations are listed in the Notation (Appendix F).

<sup>2</sup> Philosophical lunchtime discussion with Dr. N. Kraus, CERC.

<sup>3</sup> M. R. Gourlay, 1968, "Beach and Dune Erosion Tests," unpublished report, Delft Hydraulic Laboratory, The Netherlands.

that the parameter seemed to correlate with the beach reflection coefficient.

29. Noda (1971) investigated both prototype-scale and small-scale model results for profile similarity and found that a much closer similarity could be obtained if the  $H/wT$  parameter was conserved than if wave steepness,  $H_o/L_o$  (deepwater wave height divided by deepwater wave length), was held constant between model and prototype. He also offered an empirical relationship for the selection of model grain sizes and concluded that movable-bed coastal models could be distorted, but the validity still needed to be confirmed.

30. Dean (1973) popularized the fall speed parameter by incorporating it into an expression for distinguishing between swell and storm profiles. Dean used mostly small-scale movable-bed model results to establish an empirical coefficient for his expression. This coefficient was later revised by Kriebel, Dally, and Dean (1986b) by the addition of more prototype-scale data and reevaluation of the results. They concluded that Dean's original results reflected significant scale effects. Kriebel, Dally, and Dean (1986b) extensively reviewed the literature on parameters pertaining to differentiating between swell and storm profiles.

31. Dalrymple and Thompson (1976) plotted foreshore beach slope as a function of the fall speed parameter using laboratory data available from both small- and large-scale experiments. Their plot indicated the importance of the parameter in governing beach slope, although considerable scatter appears about the trend. They reported that similar attempts to relate beach slope to other parameters exhibited greater scatter; hence the fall speed parameter performed best in their study.

32. Gourlay (1980) investigated equilibrium beach profiles in the laboratory using fine sand and coarse-grained crushed coal for bed materials. The results reaffirmed the contention that the fall speed parameter is an important parameter influencing both surf zone hydrodynamics and the resulting equilibrium profile. He also concluded that the initial profile impacts the final profile only when the initial slope is quite mild. Gourlay stated that the fall speed parameter is probably sufficient for defining similarity conditions for model beaches formed in relatively impermeable sand, but the parameter would not be sufficient for defining similarity conditions for model beaches in permeable conditions, such as crushed coal. For highly permeable beaches, Gourlay stated the ratio of flow speed within the deposited sediment to the sediment fall speed in still water is also important.

33. The fall speed parameter has also been used to characterize geometric profile features such as breakpoint bars and troughs, shoreline-to-bar-crest distance, etc. Hughes and Chiu (1981) based their profile parameterizations on small-scale movable-bed model experiments, and more recently Larson and Kraus (1989) used results from two prototype-scale wave tank experiments to characterize barred profiles and develop a cross-shore sediment transport numerical model. In both cases, the fall speed parameter figured prominently in the profile parameterizations.

# Suggested Scaling Criteria Based on Fall Speed Parameter

## Previous Efforts

34. Dalrymple and Thompson (1976) were among the first to propose movable-bed modeling criteria that maintained similarity between prototype and model values of the fall speed parameter. Several sets of scaling criteria were developed by Dalrymple and Thompson, and some were tested in the laboratory. Among their more interesting findings were that the foreshore slope appeared to be independent of the initial profile and that the experimental results were repeatable. One of the developed model laws required an undistorted model with the waves scaled according to the Froude criterion and sand grain size selected to preserve the prototype value of the fall speed parameter. This law was not tested in the laboratory, but Dalrymple and Thompson stated that it appeared to be most practical because it also preserves the wave steepness parameter. Additionally, they recommended the model bed material be sand to avoid possible "alien" effects.

35. Kamphuis (1982) concluded that preservation of the fall speed parameter eliminates most of the scale effects associated with attempting to geometrically scale the grain size diameter of quartz sand.

36. Vellinga (1982) presented distorted movable-bed modeling guidance for dune erosion that incorporated sediment fall speed. Correct distortion in the model was determined through a scaling series involving 24 small-scale tests with various combinations of three length scales and four sediment sizes along with some prototype-scale laboratory experiments. Irregular wave trains were used during testing. These model results were used to determine empirical exponents in the scale relationships. In considering the undistorted version of Vellinga's scaling relationship, the guidance is equivalent to preserving the fall speed parameter in an undistorted Froude model.

37. Hughes (1983) also proposed a distorted model law for movable-bed models of dune erosion that was derived specifically to preserve the fall speed parameter. Model distortion was achieved by modifying the time scale from the Froude requirement so that trajectories of falling particles remained in similitude. Although the scaling relationships differed with that of Vellinga (1982), the undistorted versions of both model laws were identical and conformed to that recommended by Dalrymple and Thompson (1976). Discussions of the distorted model law were presented by Sayao (1984) and Vellinga (1984). Hughes (1984) recommended the undistorted version of the model law be used when possible so that the wave steepness would also be in similitude.

38. Sayao and Guimaraes (1984) reviewed previous distortion relationships for movable-bed beach profile models and tested four similarity criteria in a two-dimensional (2-D) wave tank. Their results indicated an influence of the fall speed parameter relative to a critical value representing demarcation between onshore transport and offshore transport. They recommended that it was necessary for both

model and prototype values to be in the same range (either above or below the critical value), but did not require similarity of the fall speed parameter between prototype and model. However, they recommend that further tests using fine-grain sediment be undertaken to evaluate the influence of the fall speed parameter. Tests conducted using lightweight cellulose acetate were not successful, and they recommended avoiding these types of model sediments for beach profile modeling.

39. Dean (1985) reviewed previous movable-bed modeling criteria and considered the dominant physical mechanisms involved in surf zone sediment transport. He argued that the Shield's criterion need not be met in the surf zone because turbulence, not bed shear, is the dominant cause of sediment mobilization; and therefore, bed shear is not an important consideration above Reynold's numbers constituting the fully rough range. Dean made specific recommendations for successful modeling of surf zone processes:

- a. Undistorted model (equal horizontal and vertical length scales).
- b. Hydrodynamics scaled according to Froude similarity.
- c. Similarity of the fall speed parameter between prototype and model.
- d. Model is large enough to preclude significant viscous, surface tension, and cohesive sediment effects so that the character of the wave breaking is properly simulated.

40. Dean (1985) argued that, in an undistorted model, the fall trajectory of a suspended particle must be geometrically similar to the equivalent prototype trajectory and fall with a time proportional to the prototype fall time. This is accomplished by ensuring similarity of the fall speed parameter between the prototype and the undistorted model. Dean noted that similarity of sediment fall trajectory could also be achieved in distorted models, but he did not recommend distorting movable-bed models because of uncertainties involved if sediment fall speed is not scaled according to the Froude criterion. An additional concern is the possibility of dissimilar hydrodynamic surf zone conditions between prototype and model when distorted scaling is introduced. Dean evaluated his recommendations with intuitive reasoning and by examination of past results in light of the suggested criteria. He concluded by stating, "More extensive data are required to establish further the degree of validity of the proposed modeling criteria."

41. Vellinga (1986) thoroughly detailed his own work and the work of others in the areas of dune erosion and movable-bed scale modeling. He examined many of the suggested parameters for characterizing surf zone processes, and he reviewed various methods for developing potential scaling guidelines. Large-scale model tests, with irregular waves having 2-m significant heights, were used to verify the previously developed (Vellinga 1982) scaling criteria. The distorted model scaling criteria were tested in a three-dimensional (3-D) situation having vertical scale of 60 and horizontal scale of 120 over straight depth contours. Results confirmed the 2-D development within acceptable limits (Vellinga 1986). Small-scale, 2-D undistorted tests with Froude scaling of the hydrodynamics compared very well with large-scale tests having the same value of fall speed parameter, showing geometrically similar profile development. Vellinga



concluded that Froude scaling of the hydrodynamics is necessary so that wave steepness is not distorted, the fall speed parameter should be constant between prototype and model, and wave heights should be as large as possible. These are precisely the criteria suggested by Dean (1985).

42. Kriebel, Dally, and Dean (1986a) adopted the criteria given by Dean (1985) to examine profile erosion and accretion characteristics in a 2-D movable-bed model. (Greater detail is given in Kriebel, Dally, and Dean 1986b.) They pointed out that the scaling criteria are not universally accepted; however, preservation of the fall speed parameter had been used successfully by others. They supported undistorted models by noting that in undistorted models

... ambiguous definitions of length and time scales are eliminated, unrealistic augmentation of gravity forces are avoided, and interpretation of all physical quantities is clarified.

43. Kriebel, Dally, and Dean (1986a) examined the validity of the proposed scaling guidance by attempting to reproduce the profile development observed by Saville (1957) in a prototype-size wave tank using uniform waves. The scale model bed material was quartz sand with a mean diameter of 0.15 mm. Application of the fall speed parameter criterion with undistorted hydrodynamic scaling gave a length scale of 9.6, corresponding to a prototype grain size diameter of 0.4-mm quartz sand. Reproduction of the selected erosive condition from Saville's prototype-scale tests showed good overall profile development in the bar and trough and offshore geometry, lending credibility to the scaling guidance for the energetic erosive condition. Similar attempts to reproduce the selected accretive test case were not successful. Kriebel, Dally, and Dean (1986a) noted that the wave generator in their experiments was not sufficient to reproduce the scaled longer period waves, and reflections in the flume caused reflection bars that seemed to "lock up" sediment. Their detailed report (Kriebel, Dally, and Dean 1986b) indicates noticeable cross-tank profile variation due to the longer swell-type wave conditions. Trial tests with irregular wave trains were reported to reduce wave reflection, along with bottom ripples, and they suggested this should produce better results in accretive model tests. Erosive tests aimed at investigating the effect of the initial model profile found that the inner surf zone and beach face areas were not affected by different initial profiles, but the offshore region in the vicinity of the bar was different. This was attributed to different wave shoaling and breaking characteristics. They concluded that the scaling criteria performed well for the erosive conditions, but that realistic initial profiles must be used in physical modeling due to its effect on the incident wave characteristics. They do not recommend using movable-bed models to simulate beach recovery under regular (monochromatic) wave conditions.

44. Dette and Uliczka (1986) compared beach profile development observed in a prototype-scale wave tank with similar tests conducted at 1:10 scale. The objective of the comparison was to test validity of various scaling relationships and to examine the effects of the initial profile. The model used the same sand (grain size 0.33 mm) as was used in the prototype. Best comparisons between model and prototype were found when the model profiles were scaled to prototype using the distorted model guidance given by

Vellinga (1982); however, the good correspondence was found only in the surf zone. Offshore, the scaled-up model results were substantially too shallow. For this case, Froude time scale appeared to govern the transient response, i.e., similar profile development after same number of waves. Additional tests, documented in an extended version of Dette and Uliczka (1986)<sup>1</sup> utilized model bed material having grain size of 0.17 mm. Comparisons again indicated the distortion given by Vellinga's guidance provided suitable replication in the surf zone, but not in the offshore portion. Comparisons were also made using the distortion required by Hughes's (1983) scaling criteria, with similar conclusions; but the comparison is not strictly valid because the waves in the model were run according to the Froude criterion instead of the shorter wavelength dictated by Hughes's distorted scaling of the hydrodynamics. Nonetheless, Dette and Uliczka's results indicate that better similarity is achieved if the fall speed of the sediment is used in scaling model results to the prototype. They also found that the initial profile shape seems to influence the final bar configuration, but not the inshore portion of the profile.

45. Fowler and Smith (1986) conducted small-scale movable-bed model tests to evaluate the validity of five different sets of scaling criteria. The tests were aimed at reproducing both erosive and accretive profile response documented for Saville's (1957) large-scale experiments. Different bed materials used in the 31 tests were sand (0.22 mm), crushed coal (1.2 mm), and glass beads (0.07 mm). Guidance suggested by Vellinga (1982) performed well for both accretive and erosive conditions, whereas tests scaled according to Hughes (1983) showed good correspondence only for erosive conditions. They questioned the distorting of the Froude scaling criterion as required by Hughes's guidance.

46. Fowler and Smith (1987) conducted additional small-scale tests using three sizes of sand grain and scaling the models according to Vellinga's guidance. They found that best reproduction of prototype observations were achieved with fine sand that allowed minimum model distortion. This is significant because Vellinga's guidance approaches the guidelines spelled out by Dean (1985) when distortion is minimized.

47. Sayao and Nairn (1988) endorsed the scaling guidance outlined by Dean (1985) for beach profiles by stating that the modeling requirements were "...necessary but not sufficient for dynamic similarity." They suggested that, if possible, movable-bed model design should be geometrically undistorted with Froude-scaled hydrodynamics and similarity of fall speed parameter between model and prototype. However, it is necessary to quantify remaining scale effects due to dissimilar beach slopes and nongeometrically scaled sediment diameters using prototype-scale results. They developed a morphological time scale for onshore and longshore sediment transport rates by comparison of movable-bed model results to numerical simulations, but they concluded (based on the work of Kriebel, Dally, and Dean 1986a) that the time scale for erosive offshore transport was better represented by the Froude criterion. They noted that validity of their proposed relationships was awaiting the availability of an adequate field data set.

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<sup>1</sup> Personal communication, 30 September 1988, Dr. Klemens Uliczka, University of Hannover, Federal Republic of Germany.

## Summary and Conclusions About Previous Efforts

48. The previously cited studies tend to support the preservation of the fall speed parameter between prototype and model in undistorted movable-bed models with the hydrodynamics scaled according to the Froude criterion. As Dean (1985) discussed, the model law preserves similarity in wave form, sediment fall path, wave-induced velocities, break point, breaker type, and wave decay provided the model is large enough to preclude viscous and surface tension effects. He states further that bottom shear stress will not be correctly scaled using the fall speed parameter criteria because the bottom boundary layer and ripple formations are not reproduced. This will result in noticeable scale effects when wave breaking turbulence is not dominant in the domain being modeled.

49. The successes documented by Kriebel, Dally, and Dean (1986a, 1986b) and Vellinga (1986) when specifically testing the undistorted scaling criteria under erosive conditions lends further credibility to the guidance, and this is supported by the findings of Fowler and Smith (1987) that best results occur when Vellinga's guidance is applied with minimum distortion.

50. There are definite limitations to the use of the fall speed parameter scaling criteria that restrict movable-bed modeling applications. Vellinga (1986) stated that the chance of developing universal scaling criteria applicable to both short- and long-term sediment process is slim because the short-term condition will usually require scaling of the  $H/wT$  parameter, and the long-term will probably be dominated by bed-load transport and require correct reproduction of the boundary layer shear stress. Kriebel, Dally, and Dean (1986a) noted the constraints the scaling relationships place on model facilities, stating that many prototype situations cannot be practically replicated at small scale with an undistorted model. Primarily this refers to prototype cases involving fine beach sands. The scaling guidance requires a large- to mid-scale physical model to avoid using model sediments with grain sizes approaching the transition point into cohesive sediment.

51. Opinion is divided on whether initial model profile shape significantly influences the equilibrium profile. The profile in the surf zone is well matched, but the bar region and the offshore portions appear to be impacted by initial model profile. Gourlay (1980) cites several other studies supporting both sides of the issue, but points out that the transient response is certainly affected by initial profile.

52. In conclusion, efforts aimed at reproducing surf zone profile response in small-scale movable-bed models during erosive conditions have converged on scaling criteria that preserves the parameter  $H/wT$  between prototype and geometrically undistorted model, with the hydrodynamics (waves primarily) being scaled by the Froude criterion. This scaling guidance was adopted for testing and verification in the study described by this report.

## Selected Scaling Criteria

53. The selected scaling guidance consists of simultaneously satisfying two scaling criteria in an undistorted movable-bed model. The first is the well-known Froude criterion for the hydrodynamics that arises if the ratio of inertial forces to gravity forces is held constant between prototype and model. The Froude criterion results in the relationship

$$N_t = \sqrt{N_\ell} \quad (2)$$

where  $N$  represents the prototype-to-model ratio of the subscribed parameter,  $t$  is time, and  $\ell$  is length. Note that scale ratios defined in this manner are usually greater than one and are always dimensionless. In deriving Equation 2, the gravity scale,  $N_g$ , was set equal to unity.

54. The second criterion requires maintaining similarity of the fall speed parameter between prototype and model, i.e.,

$$\frac{H_p}{w_p T_p} = \frac{H_m}{w_m T_m} \quad (3)$$

where the subscripts  $p$  and  $m$  represent prototype and model, respectively. Rearranging Equation 3 yields

$$\frac{H_p}{H_m} = \frac{w_p}{w_m} \frac{T_p}{T_m} \quad (4)$$

Equation 4 can be written in terms of scale ratios as

$$N_H = N_w N_T \quad (5)$$

55. Recognizing in an undistorted model that  $N_H = N_t$  and that the wave period will scale the same as the hydrodynamic time scale, the combination of Equations 2 and 5 results in the unique scaling relationships satisfying both criteria:

$$N_t = N_w = \sqrt{N_\ell} \quad (6)$$

## Comparison to Xie's Scaling Guidance

56. As mentioned, various parameters other than the fall speed parameter have been suggested for use in characterizing sediment transport processes. It is instructive to examine one of these parameters in more detail because it was found useful for analyzing some of the scale model results arising from this study.

57. Xie (1981, 1985) conducted numerous small-scale movable-bed model tests to examine the scouring of bed material adjacent to a vertical seawall subjected to nonbreaking waves. He observed two distinctly different responses in bed form that appeared to correspond to different mechanisms of sediment transport.

He classified Type I scour as fine bed material moving largely by suspension so that scouring occurs at the nodes of the regular standing waves and deposition occurs about the antinodes. Type II scour occurs when coarse-grained material moves as bed load, scouring sediment halfway between the nodes and the antinodes and depositing at the nodes of the standing wave pattern. After testing several parameters, including the fall speed parameter, Xie presented a criterion for distinguishing between the two scour patterns that depends on the grain size of the bed material and on the wave conditions. The criterion is based on the parameter

$$\frac{U_{max} - U_*}{w} \quad (7)$$

where

$U_{max}$  = horizontal component of the maximum orbital water particle velocity near the bed

$U_*$  = critical velocity for incipient motion of the sediment

$w$  = sediment fall speed

This parameter gives a relative comparison between the horizontal water particle speed beyond that necessary for incipient motion and the speed at which the sand grain settles. High values of the parameter imply movement by suspension (turbulence-dominated), and low values correspond to bed-load-dominant conditions. A similar parameter was proposed by Le Méhauté (1970), who stated that kinematic similarity was important for modeling beach profiles at small scale and suggested that the ratio of the horizontal component of the orbital water velocity to the sediment fall speed be maintained.

58. Xie (1981) suggested that similarity of the parameter given by Equation 7 should be maintained between prototype and model, but noted that this would be difficult at times because of the dependence of both  $U_*$  and  $w$  on grain size. Barring complete similarity, he recommended that both prototype and model at least be in the same range for the type of scour being modeled, i.e., keep the value of the parameter above 17 for Type I scour of fine sediment and below 16 for Type II scour of relatively coarse sediments. A strong correspondence between the fall speed parameter and Xie's parameter is evident and prompts further investigation.

59. The scaling criterion derived from maintaining similarity of Xie's parameter in an undistorted Froude model is developed as follows:

$$\left( \frac{U_{max} - U_*}{w} \right)_p = \left( \frac{U_{max} - U_*}{w} \right)_m \quad (8)$$

where once again subscripts  $p$  and  $m$  represent prototype and model, respectively. Rearranging Equation 8 yields

$$\frac{\left( 1 - \frac{U_*}{U_{max}} \right)_p (U_{max})_p}{\left( 1 - \frac{U_*}{U_{max}} \right)_m (U_{max})_m} = \frac{w_p}{w_m} \quad (9)$$

60. Using the notation for scale ratios and noting that, in an undistorted Froude model, the scale for the water velocity will be the same as the time scale, Equation 9 becomes

$$\frac{\left(1 - \frac{U_*}{U_{max}}\right)_p}{\left(1 - \frac{U_*}{U_{max}}\right)_m} N_t = N_w \quad (10)$$

or

$$N_* N_t = N_w \quad (11)$$

where

$$N_* = \frac{\left(1 - \frac{U_*}{U_{max}}\right)_p}{\left(1 - \frac{U_*}{U_{max}}\right)_m} \quad (12)$$

61. In essence, the scaling guidance given by Equation 10 is a more generalized version of the guidance determined with the fall speed parameter (Equation 6). The scaling guidance given by Equation 10 agrees with that given by Equation 6 if the scale ratio  $N_*$  is equal to unity.

62. Examining Equation 12, there are two conditions by which  $N_*$  could approach unity. The first is if  $U_{max} \gg U_*$  in both the prototype and model. This would be representative of highly turbulent conditions, such as exist in the surf zone during energetic wave conditions; and in the limit it corresponds somewhat to the physical description given by Gourlay<sup>1</sup> and Dean (1973) for a suspended grain falling through the water column under the influence of horizontal currents.

63. The other conditions leading to unit value for  $N_*$  is if the ratio  $U_*/U_{max}$  is kept similar between prototype and model. Although there may be unique cases where this similarity could be maintained, in general the investigator will be unable to satisfy both the fall speed scale and the grain size scale necessary to meet this condition. Even if possible, the scaling would be valid for only one specific hydrodynamic condition because  $U_{max}$  depends on wave period and wave height, whereas  $U_*$  is independent of wave height. This would hamper investigations using irregular waves, as well as studies in which numerous regular wave periods were of interest. The best achievable situation, if scaling according to the fall speed parameter guidance (Equation 6), is that where velocity ratios ( $U_*/U_{max}$ ) remain reasonably close in value for the prototype grain size and the derived model grain size.

64. The preceding discussion may help to explain why distorted model scaling guidance using bed materials similar in size to the prototype perform well in the surf zone, but suffer in the comparisons for the region seaward of breaking (Dette and Uliczka 1986, Fowler and Smith 1987). In the surf zone,  $U_{max}$  is typically much larger than  $U_*$ , and the scale ratio  $N_*$  will be approximately unity. Seaward of the wave breaking zone, model sand grains having approximately the same mean diameter as the prototype sand will undergo transition to a bed-load dominant transport mode in the model sooner than the equivalent transition in the prototype, and the seaward migration of the sand will be less in the model than in the prototype (for the case of net offshore transport conditions).

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<sup>1</sup> Gourlay, op. cit.

65. In undistorted Froude models where the model sand has been reduced in size from the prototype according to the fall speed ratio, deviations in the  $U_*/U_{max}$  velocity ratio between prototype and model will also occur offshore of the breakpoint bar. However, these deviations will be less than in the case of a distorted model employing prototype-size sand. The consequences of this offshore effect will be examined further in Part IV using specific results from the present study.

## Applicability of Selected Scaling Criteria

66. The selected movable-bed scaling criteria given by Equation 6 are for undistorted Froude models where the sediment size is selected so that the fall speed parameter is held constant between prototype and model. Past experience with these and similar scaling criteria, coupled with the assumptions used in formulating the guidance, restricts application of this type of physical modeling to coastal sediment problems and processes that are chiefly erosional in nature, with the erosion occurring in an energetic, turbulence-dominated region such as the surf zone. Typically, the scaling is intended to replicate the short-term response of the sea bed to storm-induced waves. Examples of situations that may be candidates for modeling with the selected criteria include: beach and dune profile response to storm events, initial beach-fill adjustment to larger waves, beach-fill response to storm events, and storm-related short-term scour at the toes of structures.

67. Most experience with these scaling criteria, including the present study, has been with 2-D wave flumes; hence, applicability of the guidance to the 3-D situation is still in question, although Vellinga (1986) has performed related tests in a movable-bed basin with encouraging results.

68. An unfortunate aspect of the selected modeling criteria is that often a fairly large facility will be required to successfully model prototype situations having fine-grained sediments. For example, Figure 1 is a simple nomogram for estimating length scale ratio based on Equation 6. This estimate assumes a model median sediment size of 0.13 mm, prototype and model water temperatures of 60 °F<sup>1</sup>, and quartz sand. It is readily apparent that prototype sediment sizes representative of many beaches will require length scales on the order of 10 or less.

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<sup>1</sup> A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 7.

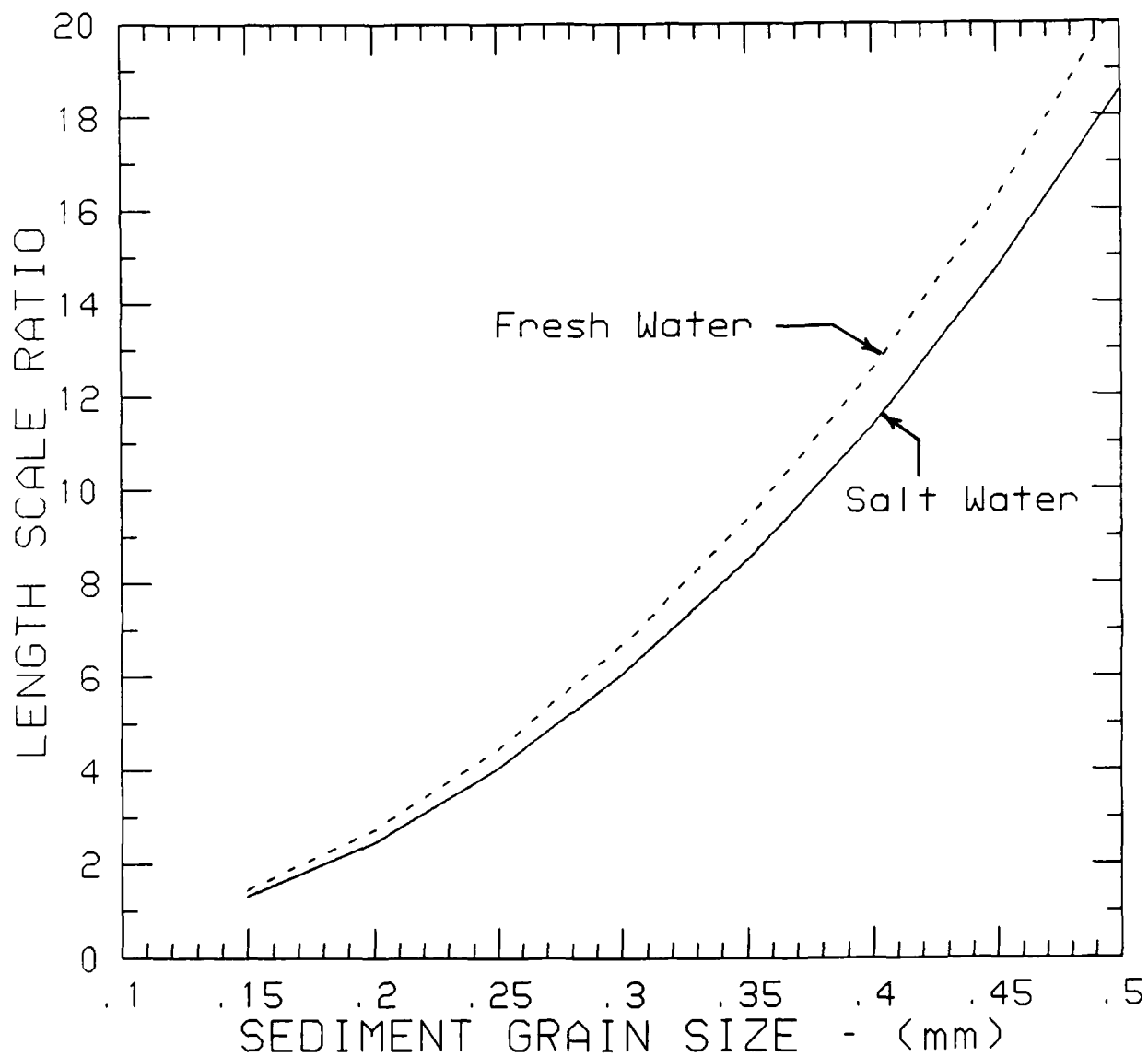


Figure 1. Nomogram for estimating movable-bed model length scale ratio



## PART III: EXPERIMENT OVERVIEW

69. This section describes the laboratory movable-bed test facilities used to verify the selected scaling criteria, summarizes the prototype condition selected for reproduction in the scaled model, presents the model scaling as determined by the scaling criteria, provides a generalized description of the testing procedure, and lists the experiments conducted over the course of this investigation.

### Laboratory Facilities

70. The majority of tests described in this report were conducted in a 6-ft-wide wave tank at the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), during the period October 1988 – January 1989. The testing was preceded by a 2-month period of model preparation and wave machine calibration. Three additional tests were conducted in the 6-ft flume during September 1989. These tests were to confirm the results of one of the earlier tests and to verify the modeling guidance by reproduction of an irregular wave prototype-scale flume test.

71. The 6-ft flume is constructed of concrete and has glass viewing panels in the test section, which is located 75 m from the wave board. Figure 2 shows a plan view of the wave tank and supporting facilities, and a profile view of the flume is given on Figure 3. The flume has dimensions and capabilities as listed in the following tabulation:

Length	100.0 m	(328 ft)
Width	1.83 m	(6.0 ft)
Depth	1.83 m	(6.0 ft)
Max. Water Depth	1.22 m	(4.0 ft)
Max. Wave Board Stroke	0.66 m	(2.2 ft)
Max. Wave Height	0.50 m	(1.6 ft)

72. The wave machine used in the 6-ft flume is hydraulically operated and is constructed such that it may be used in either the flapper or piston mode, and it can generate waves of 0.5 m at maximum operating conditions. For the reported tests, the wave machine was operated in the piston mode to generate both regular (monochromatic) and irregular waves. Figure 4 is a graphic representation of the maximum regular wave height generating capabilities of the wave generator as a function of wave period at the maximum water depth of 1.22 m.

73. Piston stroke and frequency for both regular and irregular waves are controlled using CERC software and a Micro-Vax I microcomputer. During operation of the wave generator, feedback from the

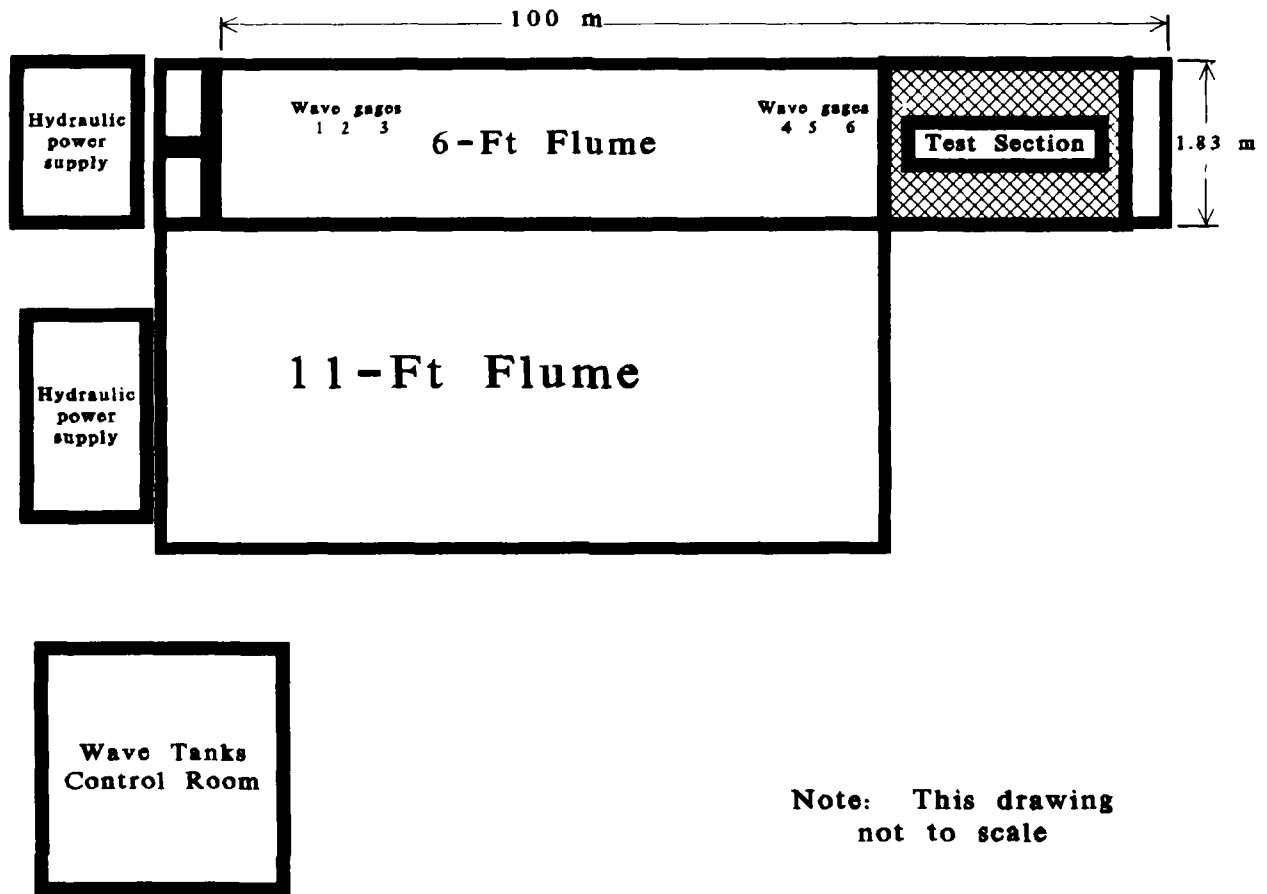


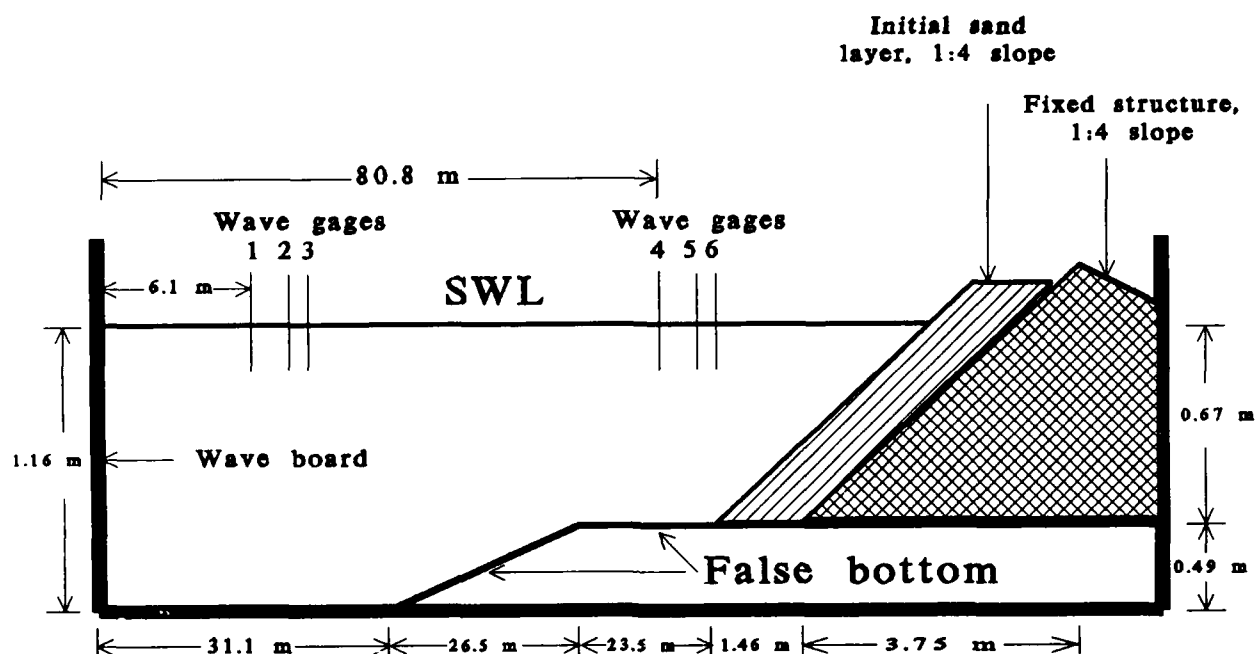
Figure 2. Plan view of 6-ft flume and supporting facilities

piston motion and wave gages is actively monitored using a multichannel oscilloscope.

74. Water surface elevations were sensed using both resistance- and capacitance-type wave rods, which were constructed at WES. The wave data were recorded on the Micro-Vax I. An Automated Data Acquisition and Control System, designed and developed at WES (Turner and Durham 1984), was used to calibrate the wave rods and to ensure correct wave height. Figure 5 is a schematic of the data acquisition system used in the 6-ft-wide flume. Six wave rods were used in two groups of three (see Figure 3) to allow calculation of reflected wave energy in the deeper water near the wave board and in shallower water near the movable-bed portion of the tank. The wave rods were calibrated at the beginning of each test series to a tolerance of  $\pm 0.002$  ft in the model.

75. To generate regular waves, a wave period and amplitude were specified and a data file consisting of sinusoidally varying stroke as a function of time was generated and used as the input signal to drive the wave machine. For irregular wave generation, software developed at CERC<sup>1</sup> was used to generate a piston

<sup>1</sup> Long, C. E., 1985, "Laboratory Wave Generation and Analysis: An Instructional Report for Unidirectional Wave Generation and Analysis," unpublished report, CERC, WES.



Note: This drawing not to scale

Figure 3. Profile view of 6-ft flume (SWL = still-water level)

stroke time-history record that produced a water surface elevation time series conforming to the input spectral representation and having significant height and peak period as specified. For regular waves, data were collected at a rate of 50 Hz whereas irregular wave data were collected at a 20-Hz rate. Wave data analysis was accomplished using a Vax 11-750 computer and software developed in-house<sup>1</sup>. Appendix A gives a summary of the analysis package used.

## Prototype Condition

76. The prototype data modeled in the tests described in this report were provided by Dr. H. Dette of Technical University of Braunschweig and Dr. K. Uliczka of the University of Hannover in the Federal Republic of Germany. These data resulted from prototype-scale tests conducted during 1985 in the large wave tank (Großer Wellenkanal or GWK) facility at the University of Hannover. The GWK has dimensions of 324-m length, 5-m width, and 7-m depth and can generate regular and irregular waves at prototype scale. The laboratory procedures used and some test results were presented at the International

<sup>1</sup> Developed and modified by K. Turner, C. Long, and D. Ward, CERC, WES.

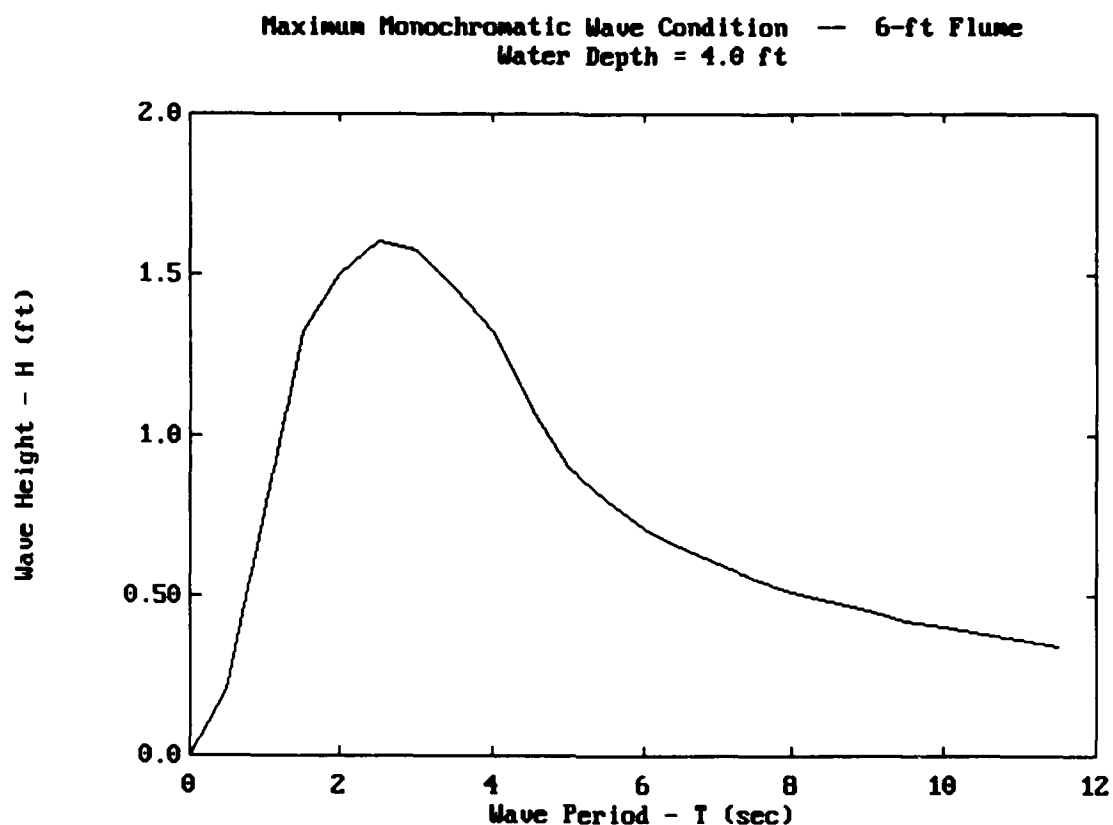


Figure 4. Wave generating capability of 6-ft flume

Association of Hydraulic Research (IAHR) Conference in 1986 (Dette and Uliczka 1986), the Coastal Sediments Conference in 1987 (Dette and Uliczka 1987), and the 21st International Conference on Coastal Engineering (Uliczka and Dette 1988). The purposes of their prototype-scale tests were to investigate dune recession and beach erosion to aid in the development of numerical models and to determine appropriate time scales for these phenomena.

77. The sand in the prototype experiments had a median diameter of 0.33 mm and was representative of sand found on the North Sea coast of West Germany. Approximately 1,000  $m^3$  of this sand was placed in front of a concrete structure with a slope of 1 on 4. The sand was molded to the same initial slope as the concrete structure shown in Figure 6. For the regular wave tests, monochromatic waves with a height of 1.5 m and period of 6.0 sec in water depth of 5.0 m were used to erode the initial profile. As many as 80 waves were generated at a time; then the wave machine was stopped and profiles were measured. Stops were made whenever the wave height variation (due to reflections) reached  $\pm 20$  percent of the originally generated wave height. The experiment was continued until little or no change was observed in profile development, indicating the *equilibrium* profile had been obtained.

78. The regular wave prototype test is somewhat unique because of the exposure of the concrete revetment during profile adjustment. Not many prototype-scale movable-bed tests have been conducted, and this test represents one of the few cases where development of a movable bed adjacent to a hard

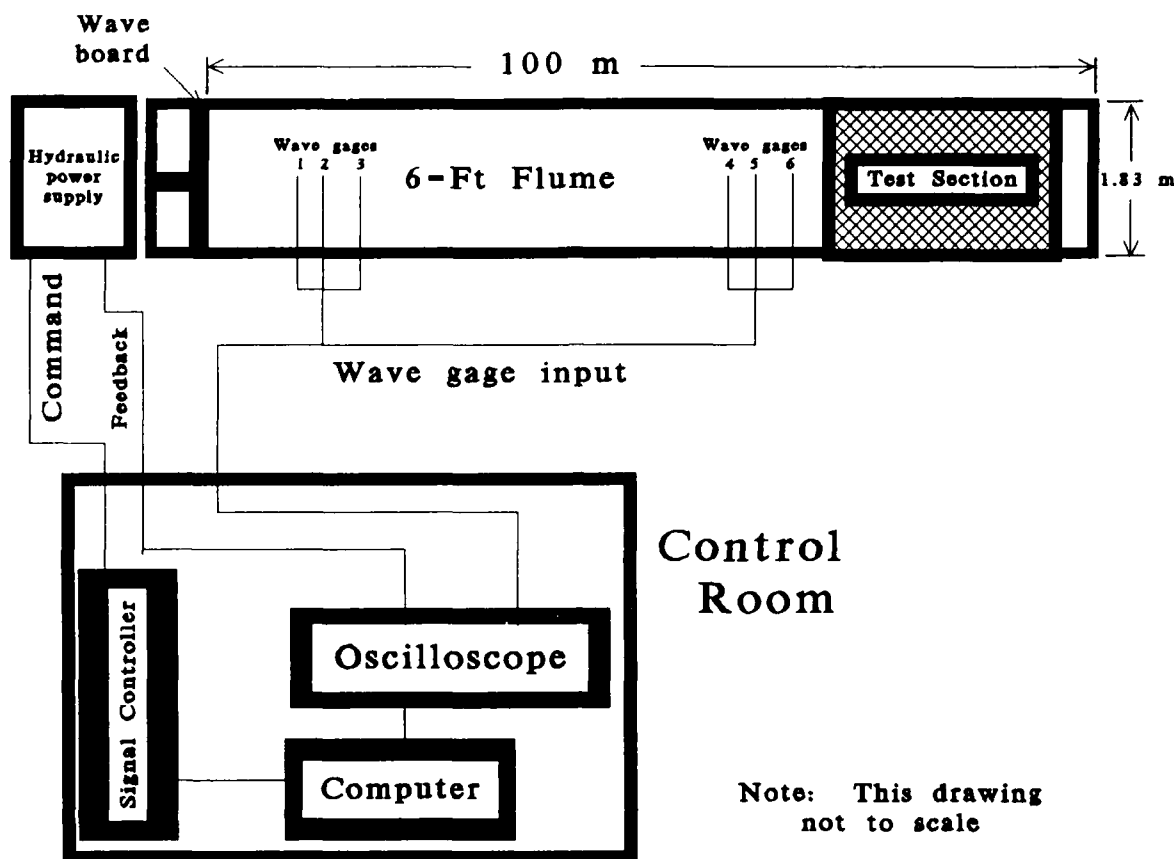


Figure 5. Schematic of data acquisition system

structure has been documented and made available to the research community.

79. In addition, Uliczka and Dette conducted several prototype-scale flume tests using irregular waves and approximately three times more sand in the profile to avoid exposing the concrete revetment. One of the cases used the same grain size and initial slope as the regular wave case shown in Figure 6. The only difference was the sand berm width, which was three times as wide for the irregular wave test. This case was selected for reproduction during the irregular wave verification of the scale model relationships. In the prototype case, a JONSWAP spectral representation was used to simulate the irregular waves. Significant wave height, peak spectral period, and water depth were specified to be equal to the same wave values as used for the regular wave prototype condition.

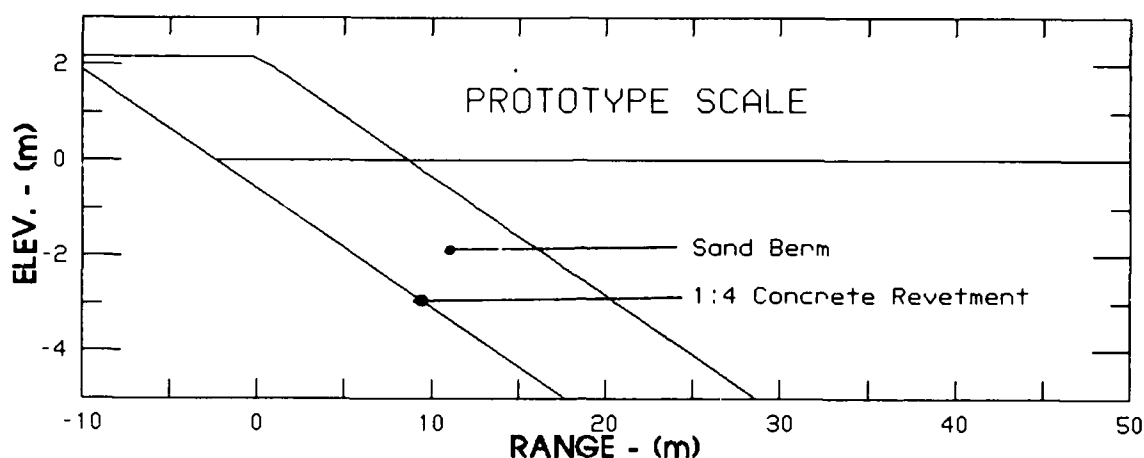


Figure 6. Regular wave initial condition

## Model Scale Selection

80. The fall speed scaling relations previously discussed and summarized by Equation 6 were used to design the movable-bed model parameters. Fine quartz sand obtained from the Ottawa Sand Company in Ottawa, Illinois, having a median diameter of 0.13 mm and specific gravity of 2.65 was used to simulate the 0.33-mm median-diameter prototype sand. The Froude scaling criterion was used to determine model wave period and the time scale for morphological development.

81. An undistorted length scale ratio of 7.5 (prototype) to 1 (model) was determined using Equation 6 and the information given in Table 1.

Table 1. Prototype and Model Sediment Parameters

Parameter	Prototype	Model
Sediment Median Diameter	0.33 mm	0.13 mm
Mean Sediment Fall Speed	4.47 cm/sec	1.64 cm/sec

82. Prototype values in Table 1 were reported by Uliczka and Dette (1988). Model mean sediment fall speed was calculated using the formulation given by Hallermeier (1981) with 0.13 mm as the diameter of the quartz sediment and assuming a water temperature of 77 °F.

83. The scale ratio for the sediment fall speed was determined as

$$N_w = \frac{4.47}{1.64} = 2.73$$

This was then used to determine both the time scale ratio and the length scale ratio as given by Equation 6, i.e.,

$$N_T = N_w = 2.73$$

and

$$N_L = N_w^2 = 7.45$$

For convenience  $N_L = 7.5$  was chosen as the length scale. Table 2 presents prototype and scaled model parameters used for the tests. Several of these parameters are illustrated on Figure 6.

Table 2. Prototype and Model Experiment Parameters

Parameter	Prototype	Model
Wave Period	6.0 s	2.2 s
Wave Height	1.5 m	0.2 m
Water Depth	5.0 m	0.67 m
Horizontal Berm Width	11.0 m	1.47 m
Berm Thickness	2.67 m	0.36 m

84. Note that strict geometric scaling using the specified prototype and model grain sizes would have resulted in a length scale ratio of  $N_L = 0.33 \text{ mm}/0.13 \text{ mm} = 2.54$ . This illustrates the utility of the fall speed parameter scaling guidance in that larger length scale ratios are permitted, thus allowing modeling to be conducted in smaller facilities. An interesting experiment would be to attempt reproduction of the selected prototype event in a large-scale wave flume using geometric scaling of the sediment between prototype and model.

## Testing Procedure

85. The procedures used for all tests were intended to duplicate the procedures used by Dette and Uliczka (1986, 1987) for the GWK tests. The initial sand slope was smoothed to a 1-on-4 slope (as

illustrated in Figure 6) using a scrape and trowel, and initial profiles were taken. As previously stated, wave rods were calibrated to  $\pm 0.002$  ft tolerance prior to each test to ensure accuracy of recorded wave data. As was done in the prototype tests, regular waves were run in short bursts to minimize the effects of re-reflection off the wave board. Irregular waves were run for times equal to the scaled equivalent of the prototype wave runs. Time for water surface stilling was allowed between runs. Reflection coefficients measured during the tests at the gages nearest the wave board ranged from 0.06 to 0.2, but wave height variation never exceeded the  $\pm 20$  percent specified for the prototype tests.

86. Center-line profiles were taken during a test corresponding to similar profile measurements in the prototype after the same number of waves. Profiles were taken along each sidewall of the flume at the conclusion of each test to document observed cross-tank variations. A graduated rod with a 2-in.-diam circular foot pod was used to obtain all center-line profiles, as shown in Figure 7. Elevations were normally obtained along the profile at 0.5-ft intervals with additional elevations recorded as necessary to document profile irregularities, such as the erosion scrap. A benchmark elevation was taken at the beginning and end of every profile measurement to ensure that vertical elevations were consistent throughout the tests. Profiles measured along the flume side walls were obtained using a surveyor's level and graduated rod. The same benchmark was used for both the center-line profiles and the wall profiles so that all profiles could be related to a common datum.

## Model Experiments

87. A total of 14 tests were conducted in the 6-ft flume at CERC during the two test series documented in this report. Test identification numbers, brief descriptions of each test, and reference to the section of the report that discusses test results are given in Table 3.

88. Representative results are presented in the following report sections to illustrate observed profile development. Complete results are given in the report appendices. Wave analysis results for each experiment are given in Appendix B, the experiment profile data are tabulated in Appendix C, the experiment profile plots are in Appendix D, and comparison of profiles from different cases (model versus model and model versus prototype) are shown in Appendix E.





Figure 7. Profiling procedure during experiments

Table 3. Description of Laboratory Tests

Test	Description of Test	Rpt. Section
T01	Reproduction of prototype experiment using 10-m-horizontal-width berm	Part IV
T02	Repeat of T01 to demonstrate repeatability	Part IV
T03	Reproduction of prototype experiment using 11-m-horizontal-width berm (same as prototype)	Part IV
T04	Repeat of T03 with wave height increased by 10 percent to examine impact of height variations	Parts IV & V
T05	Repeat of T03 using absorbing wave paddle	Part V
T06	Repeat of T03 starting with the prototype profile at 40 waves molded in the flume	Part V
T07	Repeat of T03 with wave period decreased 10 percent to examine impact of period variations	Part V
T08	Repeat of T03 using irregular waves having $H_{1/3}$ equal to 140 percent of monochromatic wave height	Part VI
T09	Repeat of T03 using irregular waves having $H_{1/3}$ equal to the monochromatic wave height	Part VI
T10	Repeat of T03 using regular waves with a vertical seawall on the revetment	Part VII
T11	Repeat of T10 using irregular waves with $H_{1/3}$ equal to the monochromatic wave height	Part VII
T12	Undocumented repeat test of T08	None
T13	Aborted irregular wave test	None
T14	Reproduction of prototype irregular wave test	Part IV

## PART IV: VERIFICATION TESTS

89. Verification of the selected movable-bed scaling criteria by reasonable reproduction of prototype test profiles was the primary purpose in conducting the experiments discussed in this report. No clear quantitative guidance has been given for determining what constitutes *successful reproduction* in the model, although Dean (1985) lists reproduction of the correct beach slope and type of profile (barred or nonbarred) as good indicators of the relative success of the attempt. Generally, a visual comparison between prototype and model profiles, supplemented by some type of parameter describing the variations between profiles, forms the basis for a subjective opinion as to whether or not the experiment has been successful.

### Regular Wave Validation Test

90. The first two tests performed (T01 and T02 in Table 3) were conducted with a sand berm having a scaled horizontal width equivalent to 10 m in the prototype (see Figure 6). After completing these two tests, plotted results indicated a discrepancy in volumes of sand between model and prototype. It was subsequently discovered<sup>1</sup> that the prototype berm was actually 11 m in the horizontal dimension, slightly greater than the nominal horizontal width given as 10 m. Hence, the tests T01 and T02 represented a berm having approximately 10 percent less sand than the actual prototype berm. These tests will be discussed later in relation to experimental repeatability and impacts of reduced or inadequate sediment supply.

### Test T03 Results

91. Test T03 represents the best attempt to reproduce every aspect of the prototype experiment in accordance with the selected scaling criteria. Summary wave statistics resulting from analysis of water level fluctuations recorded at the two gaging locations are given for Test T03 on Table B3 in Appendix B. (A description of the wave analyses procedures is given in Appendix A.) Time series wave statistics in Table B3 refer to the average of the results obtained from the three gages comprising the array at each location. Spectral values ( $H_{m0}$ ,  $T_p$ , where  $H_{m0}$  = zeroth-moment wave height and  $T_p$  = period of spectral peak) represent the incident wave condition after removal of reflected wave components.

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<sup>1</sup> Personal communication with Dr. Klemens Uliczka confirming horizontal berm width used in prototype case, 28 December 1988.

92. Figure 8 shows the developmental response of the center-line profile in the model. The solid line is the model profile measured after the specified number of waves, and the dashed line is a model profile measured at an earlier point in the experiment. The purpose of Figure 8 is to illustrate the relative change of the center-line profile as it approached equilibrium. A complete set of profiles for test T03 is given in Figure D3 in Appendix D, and the profile measurements are given in Table C3 in Appendix C.

93. For regular waves, the profile reached a quasi-equilibrium condition somewhere between 1,200 and 1,400 waves with very little change occurring thereafter. The most noticeable change occurring after 1,400 waves was an observable cross-tank variation in the profile. This variation is shown in Appendix D (Figure D3) by the plots comparing profiles at 1,650 waves. In these plots, the suffix P represents the center-line profile (dashed) while G and C represent profiles along the glass sidewall and the concrete sidewall, respectively. Figure 9 plots the average of all three profiles after 1,650 waves as compared with the center-line profile (dashed).

94. This cross-tank variation is thought to have been caused by a small misalignment of the revetment in the flume which in turn caused nonuniform reflection of waves from the exposed concrete revetment. Similar cross-tank variation was not present in the prototype-scale tests of Dette and Uliczka<sup>1</sup>. It was noted that the cross-tank variation in the model did not materialize until after the profile was close to an equilibrium condition, even though the revetment was exposed somewhat earlier. This may indicate that the profile is more susceptible to cross-tank perturbations when the profile has reached a quasi-equilibrium state. If the profile is not close to equilibrium, the onshore/offshore movement of sand seems to overwhelm any cross-tank-induced sediment transport, indicating that storm-induced profile adjustment exhibits a strong onshore/offshore trend<sup>2</sup>

## Comparison with Prototype

95. Representative profile comparisons between prototype and model after equal numbers of waves (Froude scale for morphological development) are given in Figure 10. In these plots the model results have been scaled up to prototype dimensions using the length scale ratio of 7.5. A complete set of profile comparisons is given in Figure E2 in Appendix E (Test T03 versus Prototype).

96. The comparison after 40 waves (Figure 10) shows that profile development in the model did not match the development in the prototype for the underwater portion of the profile. The form of the prototype profile suggests that massive slumping may have occurred in the prototype, although this has

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<sup>1</sup> Personal Communication, Dr. Klemens Uliczka, 28 December 1988

<sup>2</sup> This trend was also observed in the field during the DUCK85 experiment (Howd and Birkemeier 1987). A prestorm breakpoint bar that exhibited nonuniform alongshore variation became quite linear and moved offshore during the storm. Near the end of the storm, when presumably a near-equilibrium had been reached, alongshore variation in the bar began to reappear.

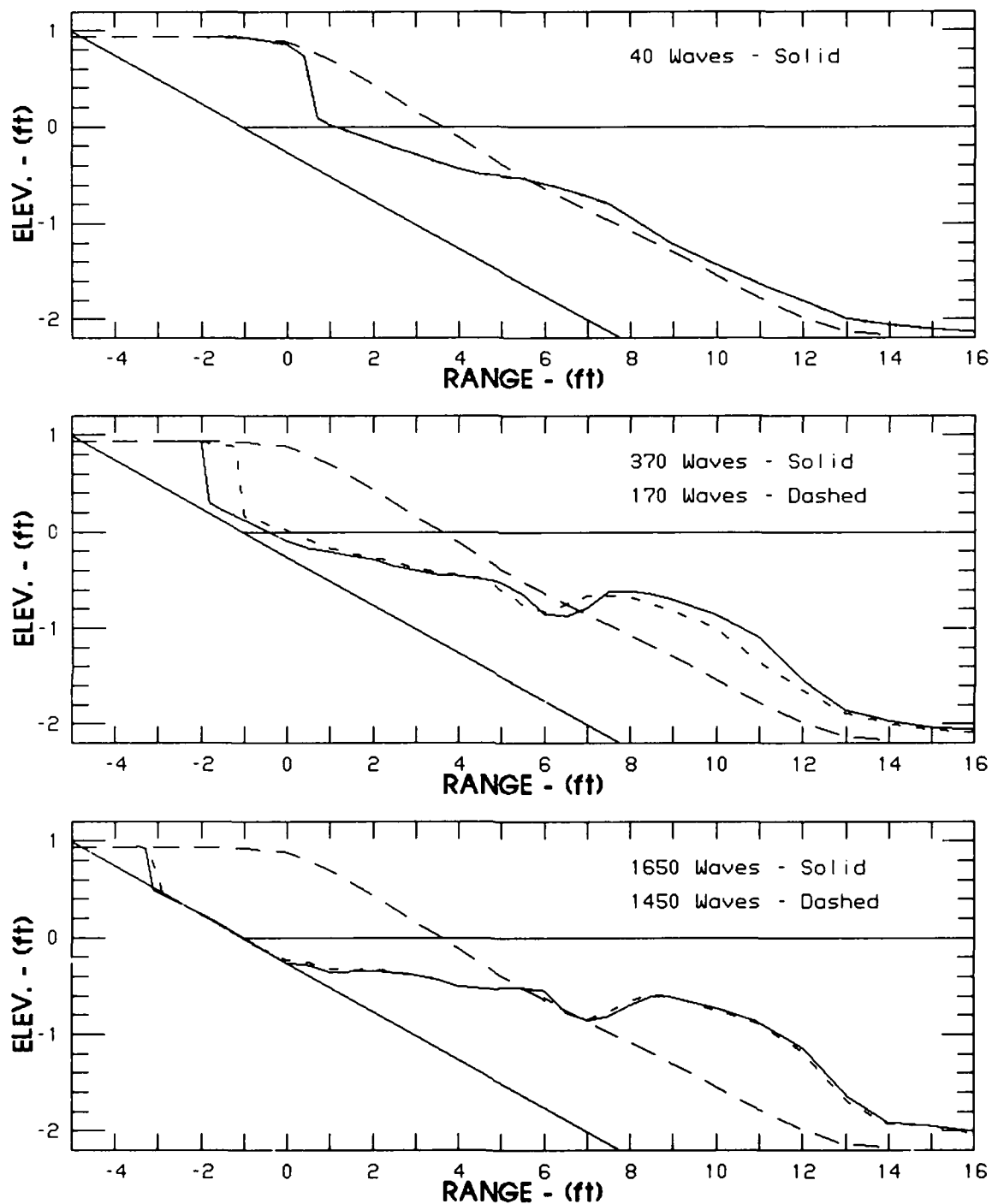


Figure 8. Profile development during test T03

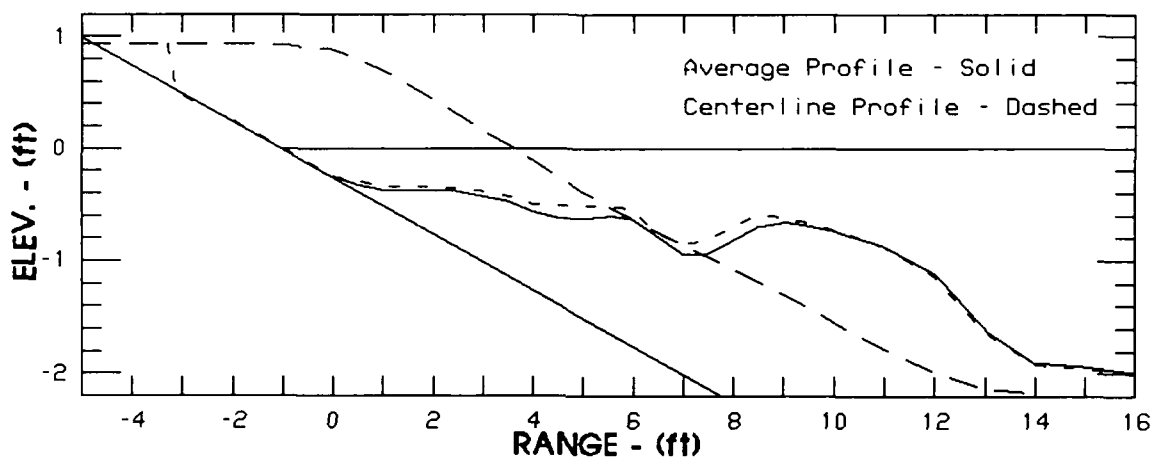


Figure 9. Average versus center-line profile at 1,650 waves, T03

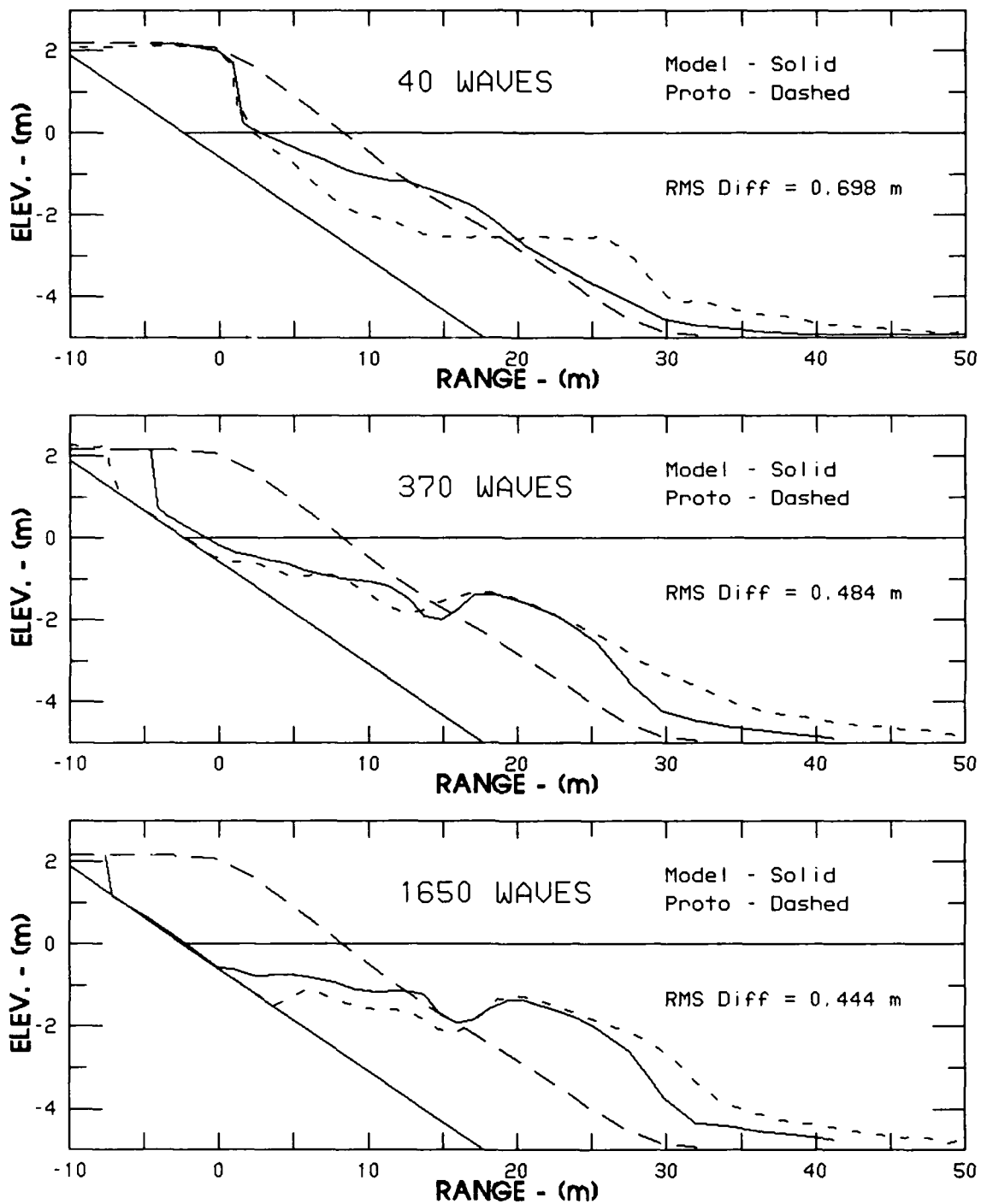


Figure 10. Prototype-model comparison for test T03 (RMS = root-mean-squared)

not been confirmed. The model, as scaled, cannot correctly simulate this type of geotechnical failure, if indeed this was the cause of the prototype profile shape after 40 waves.

97. An RMS variation between profiles was calculated for the vertical variations between prototype and model using the formulation:

$$\text{RMS Variation} = \sqrt{\frac{1}{n} \sum (h_p - h_m)^2} \quad (13)$$

where  $h_p$  and  $h_m$  are the prototype and model profile elevations at equivalent horizontal positions. The RMS variation for the comparison after 40 waves was 0.70 m, which implies a reproduction accuracy of  $\pm 0.35$  m.

98. The profile comparison after 370 waves (Figure 10) is somewhat better, having an RMS variation of 0.49 m. The berm in the model was not eroded as much as in the prototype, and not as much sediment was moved to the region seaward of the breakpoint bar. The profile comparison in the surf zone and in the vicinity of the bar is quite good.

99. The center-line profile after 1,650 waves (Figure 10) represents the equilibrium condition for this test. The RMS variation for the 1,650 wave comparison was 0.44 m when the model center-line profile was used. This RMS variation was slightly reduced to 0.40 m when the average profile (Figure 9) was used in the comparison. The model did not succeed in eroding the final portion of the berm on the upper portion of the revetment. There are two possible explanations for this. First, the concrete revetment in the model had a rough finish that, when scaled to prototype, would be much rougher than the concrete revetment used in the prototype tests. This may have limited the extent of wave runup in the model due to frictional effects. Wave runup may also have been influenced by the difference between prototype and model in the offshore portion of the profile which could have affected wave characteristics.

100. Another difference between model and prototype is that the model did not succeed in moving enough sediment to seaward of the breakpoint bar, and consequently the scouring in the surf zone was not as severe as evidenced in the prototype.

101. The observed difference between prototype and model in the region offshore of the bar is most likely a result of the scaling relationship selected. This scaling relationship works best for regions dominated by turbulence-induced sediment transport. Because the model sand grains are not scaled according to the geometric length scale, they undergo a transition from suspended mode to bed-load mode of transport before this transition occurs in the equivalent prototype flow regime. With the selected scaling criteria, the bed-load mode of transport is not properly scaled in the model; consequently the model sand grains are at rest under scaled conditions that still result in offshore sediment transport in the prototype. This concept is further examined in the next subsection.

102. The observed difference between prototype and model in the surf zone may be related to the aforementioned differences in the offshore portion of the profile. If the offshore bar has a *sediment storage capacity* under a given wave condition, and sediment to meet this capacity must come primarily from the



nearshore region, then it may be that the surplus of sand observed in the model surf zone was a result of the offshore sediment requirement having been met. If this is true, it follows that exact reproduction in the model will require correct development of the bar feature and sediment volume in the bar. Several of the additional tests in this model series were designed to investigate this possibility, and they are discussed in later sections of this report.

103. A second contributing factor to the nearshore model results may have been the aforementioned difference in maximum runup between model and prototype. Greater wave runup should contribute to the corresponding downwash on the face of the revetment, which in turn influences the amount of scouring that occurs at the interface of the structure and sediment. However, this factor is thought to be less important than the equilibrium state of the offshore bar.

## **Test with Increased Wave Height**

104. Test T04 was the first of several tests conducted to investigate the relative influences of selected model parameters on the model scaling. In test T04, the wave height in the model was increased by approximately 10 percent over the scaled equivalent of the prototype wave height that was used in test T03.

### **Test T04 Results**

105. Test T04 was also conducted in the same manner as the prototype-scale regular wave test. Figure 11 illustrates the temporal development of the profile in the model. Comparisons in Figure 11 are to earlier profiles in this same model test. Wave data and statistics for this test are given in Table B4 (Appendix B), profile data are given in Table C4 (Appendix C), and a complete set of profiles for this test is given in Figure D4 in Appendix D.

106. Similar to test T03, test T04 also exhibited a cross-tank profile variation as the test approached equilibrium as shown by the profiles in Appendix D (Figure D4). Increased wave heights apparently made the cross-tank variation a little more severe than observed in test T03. Figure 12 shows the average model profile at 1,650 waves compared with the center-line profile.

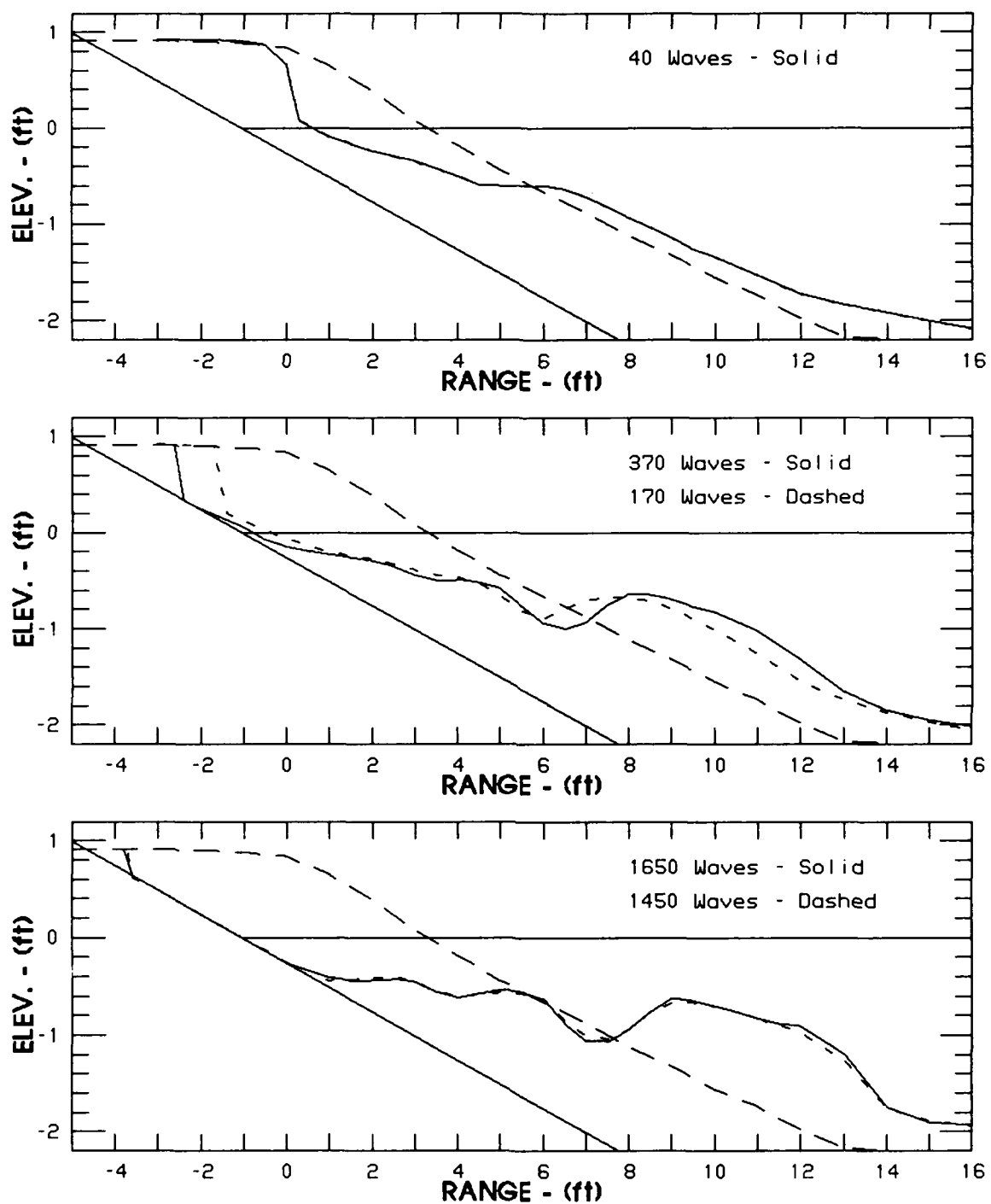


Figure 11. Profile development during test T04

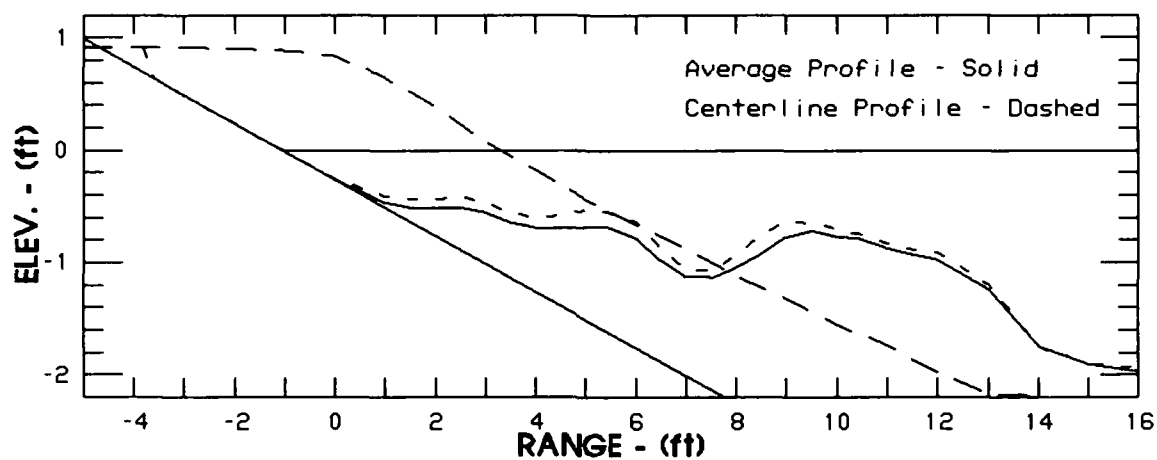


Figure 12. Average versus center-line profile at 1,650 waves, T04

## Comparison with Prototype

107. Representative profile comparisons between prototype and model after equal numbers of waves are given in prototype dimensions on Figure 13. A complete set of profile comparisons is given in Figure E3 in Appendix E (Test T04 versus Prototype).

108. The net effect of increased wave height after 40 waves is slightly more erosion of the berm and more transport of sediment into the deeper portion of the profile. Calculated RMS variation between prototype and model after 40 waves was 0.64 m (compared with 0.70 m for test T03).

109. The model comparison to prototype after 370 waves is judged as being very good with an RMS variation of 0.38 m (compared with 0.49 m for test T03). At this point, more of the berm had been eroded than in test T03 (see Figure 10), and a good correspondence is also seen in the surf zone and in the offshore region.

110. The center-line profile after 1,650 waves, when near-equilibrium had been achieved, showed a very favorable reproduction of the prototype profile development. The RMS variation calculated for this comparison was 0.30 m (compared with 0.44 m for test T03), whereas comparison with the model average profile at 1,650 waves (Figure 12) produced an RMS variation of 0.36 m (0.40 m for test T03).

111. Test T04, with the wave height increased 10 percent over what should represent the equivalent scaled model wave height, produced better comparisons to the prototype case. The increased wave-induced water velocities in the offshore region appear to have transported sediment in the model to a greater offshore depth that more closely corresponds to the prototype. This increased *sediment demand* was met by the removal of more sand in the nearshore region; consequently, better profile reproduction, both in the final equilibrium and in the developmental stages, was achieved.

## Experiment Serendipity

112. The fortunate discovery that a 10-percent increase in model wave height provided better reproduction of prototype behavior merited further examination. The possibility that reported prototype wave conditions were 10 percent less than actually generated was immediately discounted given the care with which the prototype experiments were conducted. Instead, the differences between the prototype and model in the region offshore of the breakpoint bar were examined.

113. It was shown in Part II that the fall speed parameter scaling criterion represented a special case of the criterion developed from maintaining similarity of Xie's (1981, 1985) parameter (see Equation 8). Ideally, the scaling criterion given by Equation 10 should be preferred over the selected criterion used in this study. However, as was pointed out, this criterion is impossible to satisfy throughout the modeled regime. To examine the variation in Xie's parameter between the prototype and model, idealized

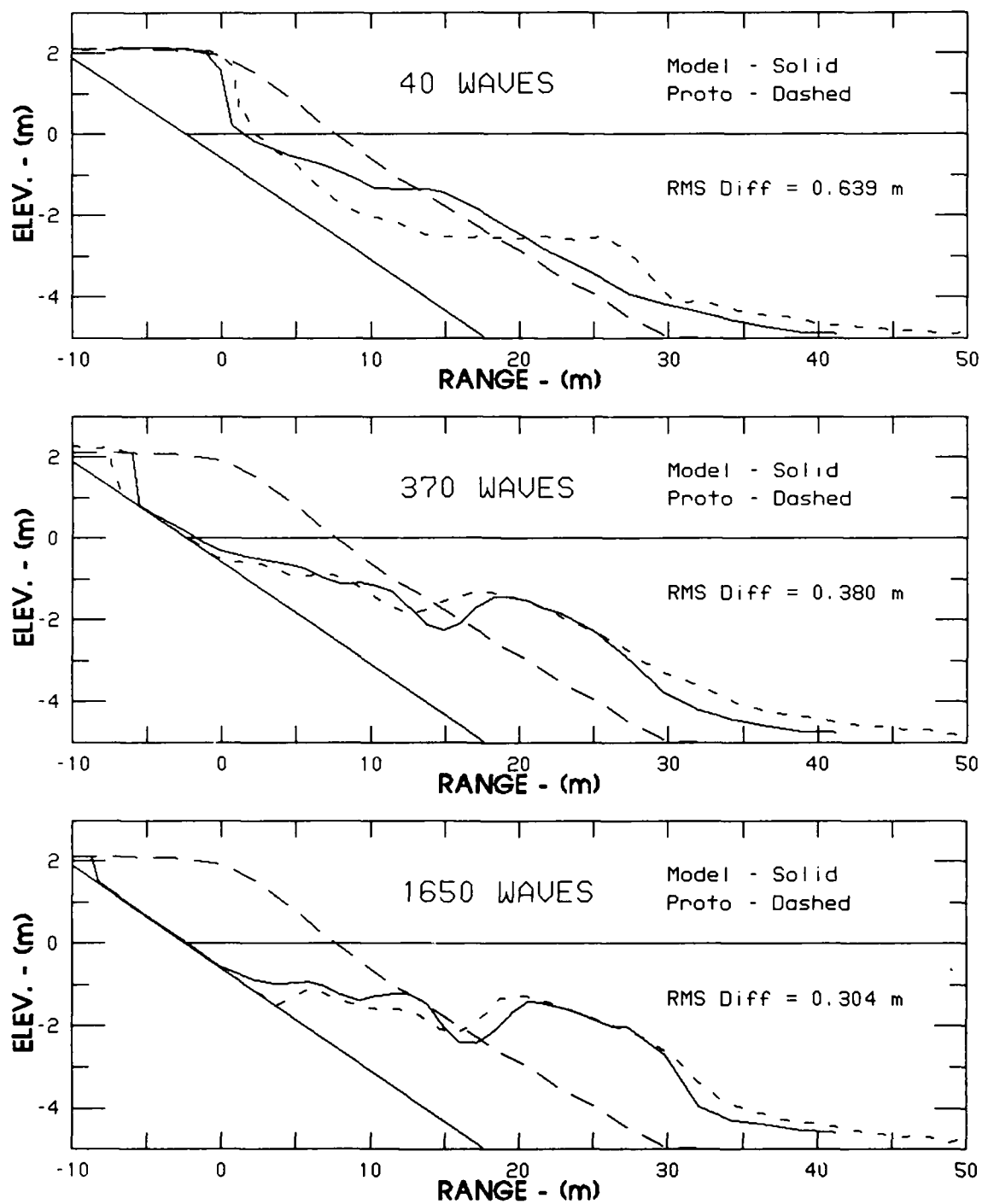


Figure 13. Prototype-model comparison for test T04

calculations of the parameter were made at different water depths in the offshore region. These calculated values, along with ratios of Xie's parameter between prototype and model for tests T03 and T04, are shown in Table 4. The maximum bottom velocity,  $U_{max}$ , was determined from the linear theory relationship

$$U_{max} = \frac{\pi H(1 + K_r)}{T \sinh\left(\frac{2\pi h}{L}\right)} \quad (14)$$

where

$H$  = wave height

$K_r$  = reflection coefficient

$T$  = wave period

$h$  = water depth

$L$  = local wave length

114. Reflection coefficients were measured in the model experiment to be about 0.5 at the nearshore gage position, and it was assumed that prototype reflection coefficients were similar. Critical velocity for sediment motion,  $U_*$ , was calculated using the relationship of Hallermeier (1980) given by

$$U_* = \frac{0.35(d_{50})^{1/4}(\gamma'g)^{3/4}}{\sqrt{\frac{2\pi}{T}}} \quad (15)$$

where

$d_{50}$  = median grain size

$\gamma'$  = immersed specific weight of sediment (about 1.65 for sand)

$g$  = gravitational acceleration

Sediment fall speed of the prototype and model sediment are given in Table 1.

115. The model values of Xie's parameter in Table 4 were calculated using the model depth equivalent to the prototype depth listed in the table. Columns 5 and 6 in Table 4 present the ratio of Xie's parameter in the prototype to that of the model. For test T03, this ratio is always greater than one, approaching unity as the depth decreases. However, the ratio for test T04 is nearer to unity over the range of offshore depths, and quite by accident, appears to be a reasonable compromise over the extent of the offshore portion of the profile.

116. The better comparison to prototype shown by test T04 suggests a modification to the selected modeling criteria that includes a procedure for adjusting the scaled model wave height in such a manner as to achieve better similarity of Xie's parameter in the offshore regions of the modeled regime. This adjustment is dependent upon the wave period and should probably be limited to the more dynamically active portion of the offshore profile rather than being extended to full depth of closure.

Table 4. Prototype and Model Values of Xie's Parameter

Prototype Depth (m)	$(U_{max} - U_*)/w$			Ratio of Xie's Parameter	
	Proto.	Base	+10%	$\frac{[(U_{max}-U_*)/w]_{proto}}{[(U_{max}-U_*)/w]_{base}}$	$\frac{[(U_{max}-U_*)/w]_{proto}}{[(U_{max}-U_*)/w]_{+10\%}}$
5.0	20.86	18.15	20.42	1.15	1.02
4.5	23.57	20.84	23.33	1.13	1.01
4.0	26.83	24.09	26.83	1.11	1.00
3.5	30.89	28.09	31.19	1.10	0.99
3.0	36.12	33.33	36.80	1.08	0.98
2.5	42.23	39.42	43.36	1.07	0.97
2.0	51.83	48.97	53.67	1.06	0.97

117. It is also noted that this experimental result pertains to regular waves, whereas the natural variability in wave height and period existing in irregular wave trains may help to compensate for the differences in Xie's parameter without augmentation of the significant wave height in the model. This possibility is investigated further in the section of this chapter discussing movable-bed model law verification employing irregular waves.

## Experiment Repeatability

118. As previously discussed, tests T01 and T02 were conducted with a smaller sand berm width than was actually required. However, these tests were conducted in an identical manner to assess the repeatability of the movable-bed model experiments. Figure 14 presents three profile comparisons between model tests T01 and T02 plotted in model units. A complete set of comparisons is given in Figure E8 in Appendix E (Repeatability Test), and profile and wave data are given in the appropriate appendices. Visual inspection of the profile comparisons indicates that the movable-bed model is very capable of producing repeatable results. In fact, examination of the comparisons at the two sidewalls after 1,650 waves reveals that the observed cross-tank variation was also reproduced to a sufficient degree of accuracy. Calculated RMS variations between the two experiments are given in Table 5. For reference, the values are given in both model units (inches) and equivalent prototype units (metres) as determined using the 7.5 length scale employed in these experiments.

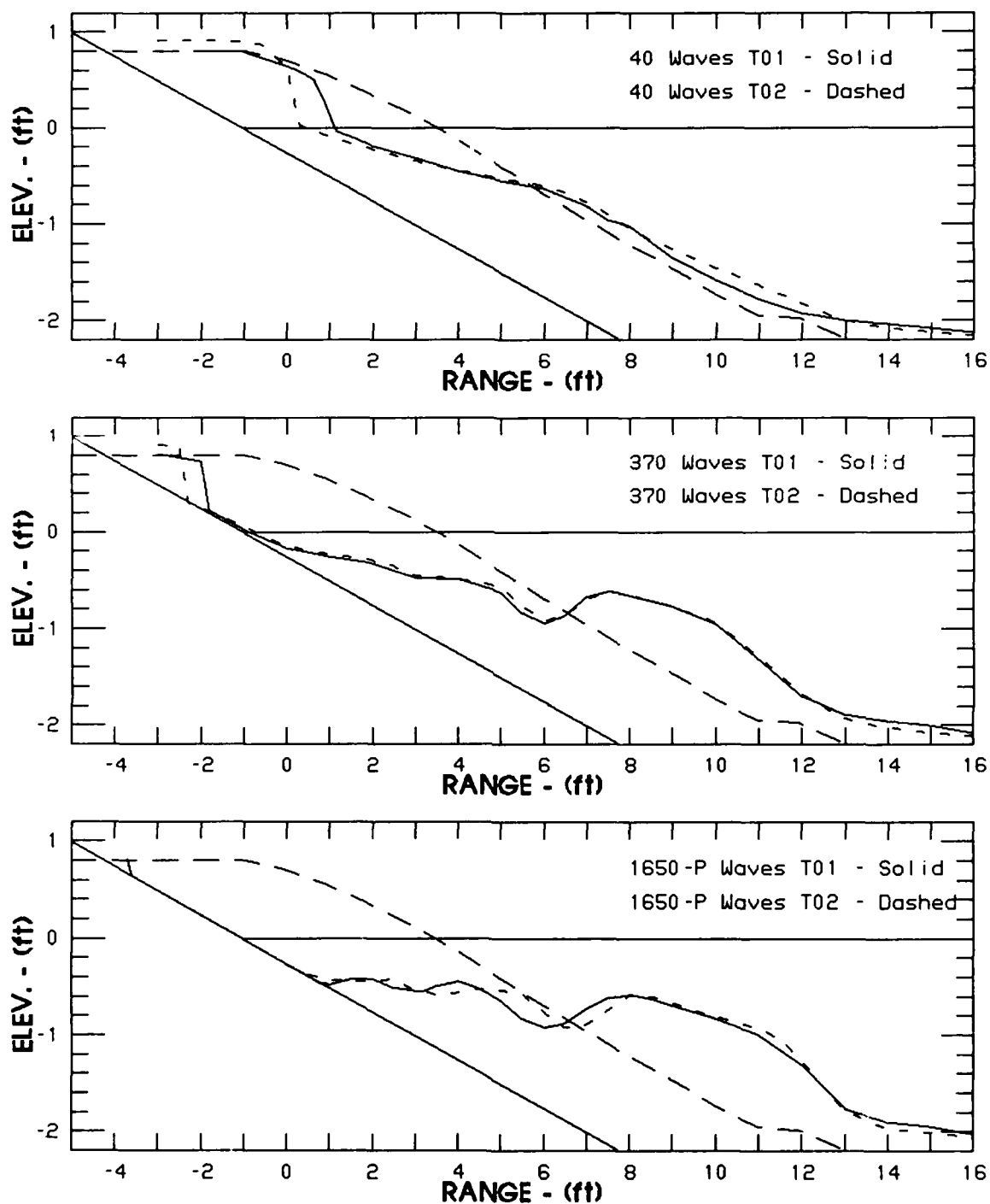


Figure 14. Repeatability test, T01 versus T02



Table 5. Repeatability Test RMS Variations

Profile Waves	Model RMS Variation in.	Prototype Equivalent RMS Variation m
40	1.9	0.36
370	1.1	0.21
1650	1.0	0.19

## Irregular Wave Validation Test

### Experiment Setup

119. Following completion of all regular wave testing in the 6-ft flume, the authors requested and received from Drs. Uliczka and Dette prototype-scale test data stemming from irregular wave tests conducted in the GWK. The prototype tests requested were conducted using the same sand (0.33 mm) as was used in the regular prototype-scale wave tests discussed earlier in this report. The primary difference between the two cases was that approximately three times as much sand was used in the irregular wave tests. This sand was a sufficient amount to prevent exposure of the sloping concrete revetment during testing as occurred during the regular wave tests. Consequently, the irregular wave tests took significantly more time to approach equilibrium, and in fact, had not reached equilibrium after nearly 7,000 waves (compare with equilibrium being reached after 1,600 waves when the revetment was exposed in the regular wave tests).

120. The irregular waves used in the prototype test series were a time series realization of a JONSWAP spectrum having an  $H_{mo}$  equal to 1.5 m and a spectral peak period of 6.0 sec. As in the regular wave tests, water depth was 5.0 m. These waves were scaled to model size using the same scaling determined for the regular wave tests. An irregular wave train was generated using CERC software that reproduced the prototype spectral parameters of significant wave height and peak period. The spectral width parameter,  $\gamma$ , in the JONSWAP spectrum was set equal to 3.3. Fine adjustment to the time series amplitude was made prior to testing to assure accurate reproduction of the scaled waves.

121. Examination of the extent of profile erosion documented in the prototype test indicated that doubling the volume of sand used in the previous regular wave tests would be sufficient to prevent exposure of the revetment and still provide adequate sand cover of the sloping revetment. Therefore, rather than increasing the sediment in the flume by a factor of three, it was increased by only a factor of two (the

advantage of *a priori* knowledge of the ultimate outcome of the experiment).

122. In the prototype-scale experiments, irregular waves were run in bursts for durations up to 12 min. The same duration sequence as was used in the prototype tests was scaled and followed in the model tests. As in the regular wave tests, time was allowed between wave bursts for the tank seiching to subside.

123. Two irregular wave tests were conducted as described above. The first (test T13) began with an erroneous command sending long period (10 sec) waves onto the initially plane-sloping beach. This error contaminated the experiment; however, the test was continued to gain experience and to assure that sufficient quantities of sand had been placed to avoid exposure of the concrete revetment. Profile data and wave data were obtained, but only a few wave records were analyzed, and none of the profile or wave data are reported herein. The second test (T14) was conducted as designed and is reported below.

## T14 Results

124. Test T14 reproduced most aspects of the prototype irregular wave experiment in accordance with the selected scaling criteria. Summary wave statistics resulting from analysis of water level fluctuations recorded at the two gaging locations are given for test T14 on Table B14 in Appendix B. (Note that the addition of sand required movement of the nearshore wave gages to maintain the same distance between gage and beach as existed for the regular wave experiments).

125. Figure 15 shows the developmental response of the center-line profile in the model. The solid line is the model profile measured after the specified number of waves, and the dashed line is a model profile measured at an earlier point in the experiment. Figure 15 illustrates the relative change of the center-line profile as it evolved. A complete set of profiles for test T14 is given in Figure D12 in Appendix D, and the profile measurements are given in Table C14 in Appendix C.

126. Unlike the regular wave tests (where the revetment was exposed), the profile under irregular waves continued to evolve throughout the duration of the test. Toward the end of the test, the flatter portion of the profile within the surf zone maintained a constant depth; and the only profile changes were due to relocation of sediment from the berm to a region offshore of the slight bar feature. Bar formation was virtually absent with only a slight crest-trough feature appearing near the end of the test series. No significant cross-tank variations were evident throughout the test. This can be attributed to the irregularity of the wave train and to the fact that the revetment was never exposed. No sidewall profiles were recorded to document this observation (However, previous irregular wave tests had exhibited similar cross-tank profile uniformity, and sidewall profiles were recorded to document the fact. These tests are discussed in Part VI of this report.)

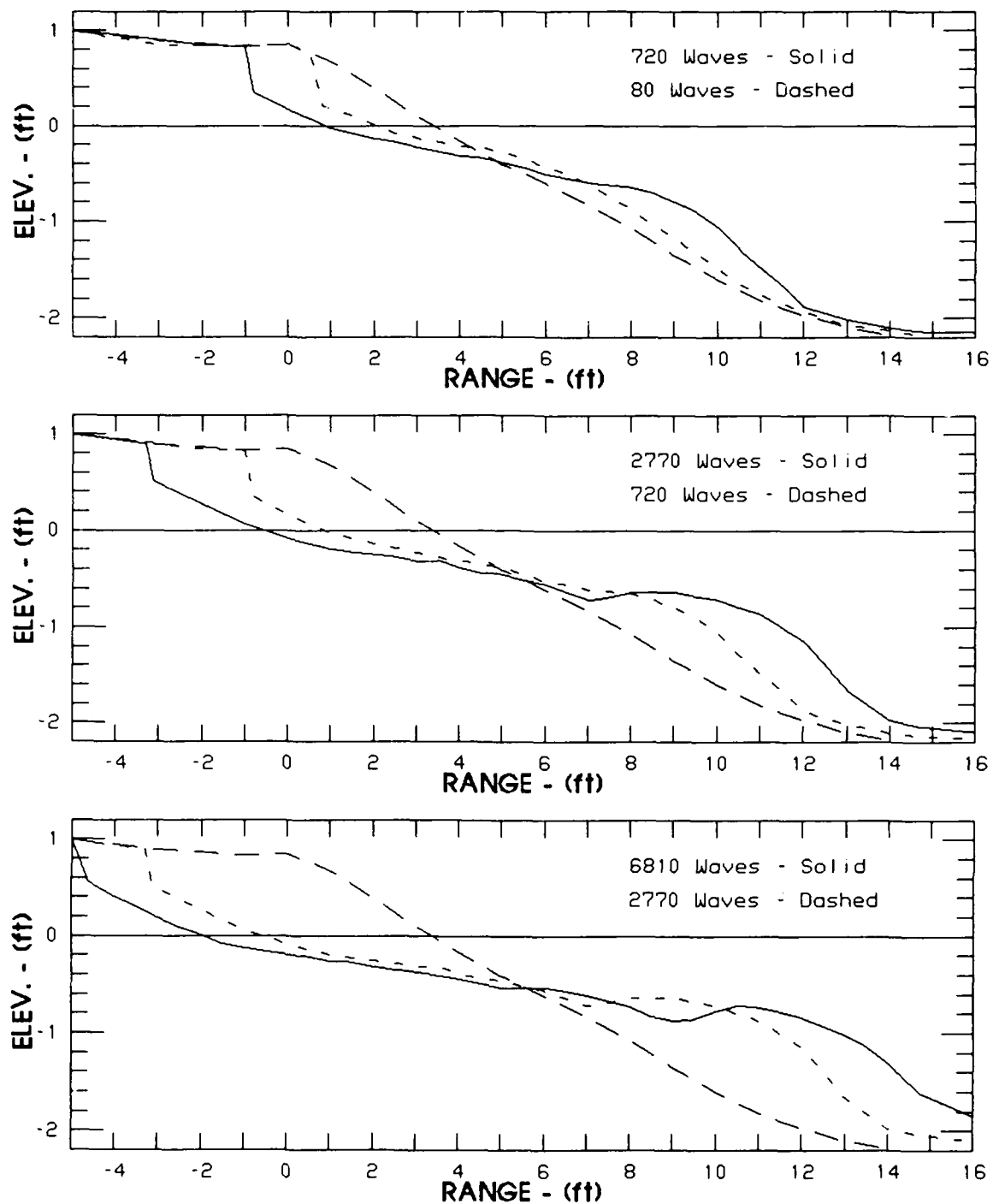


Figure 15. Profile development during test T14

## Comparison with Prototype

127. Representative profile comparisons between prototype and model after equal numbers of waves (Froude scale for morphological development) are given in Figure 16. In these plots, the model results are presented in prototype dimensions using the length scale ratio of 7.5. A complete set of profile comparisons is given in Figure E7 in Appendix E (Irregular Test T14 versus Prototype).

128. The comparison after 720 waves (Figure 16) shows that profile development in the model (solid line) closely resembled that of the prototype (dashed line) with the exception of the amount of berm recession. The calculated RMS variation between the profiles (as calculated by Equation 13) was 0.263 m. After 2,770 waves, the model continued to match the prototype response to an uncanny degree (Figure 16) with an RMS variation between profiles of 0.141 m. By the end of the test, the model profile showed some variation from the equivalent prototype profile, but the reproduction was still considered to be very good. The RMS variation between the profiles after 6,810 waves was 0.222 m. As seen in Figure 16, the model did not erode quite as deeply in the foreshore area above the still-water line, a little more sediment was carried offshore of the bar feature, and a slight bar-trough development occurred in the model that was not present in the prototype profiles.

129. The attempt to reproduce the irregular-wave prototype-scale flume experiment was considered to be very successful. This further validates the selected movable-bed modeling guidance as being appropriate for energetic regimes of sediment transport. It is significant that close reproduction was obtained over the entire extent of the profile using properly scaled irregular waves. Recall from previously presented results that the regular wave tests suggested augmentation of the model wave height to provide a better correspondence of the Xie parameter between model and prototype. Because this was not required for the case of irregular waves, it is tentatively concluded that the natural variations within the irregular wave field were sufficient to assure correct redistribution of sediment over the entire extent of the modeled profile. However, further validation of this conclusion would be desirable.

## Modeling Law Verification Conclusions

130. Visual comparisons of prototype and model profile development due to regular waves indicate that the movable-bed scaling criteria given by Equation 6 did a reasonable job of reproducing the prototype-scale profile evolution in the physical model at reduced scale (test T03). However, the model did not move as much sediment from the nearshore to the offshore region as was documented in the prototype experiment. This appears to be caused by sediment coming to rest in the offshore portion of the model under scaled conditions that would still promote bed-load transport in the prototype.

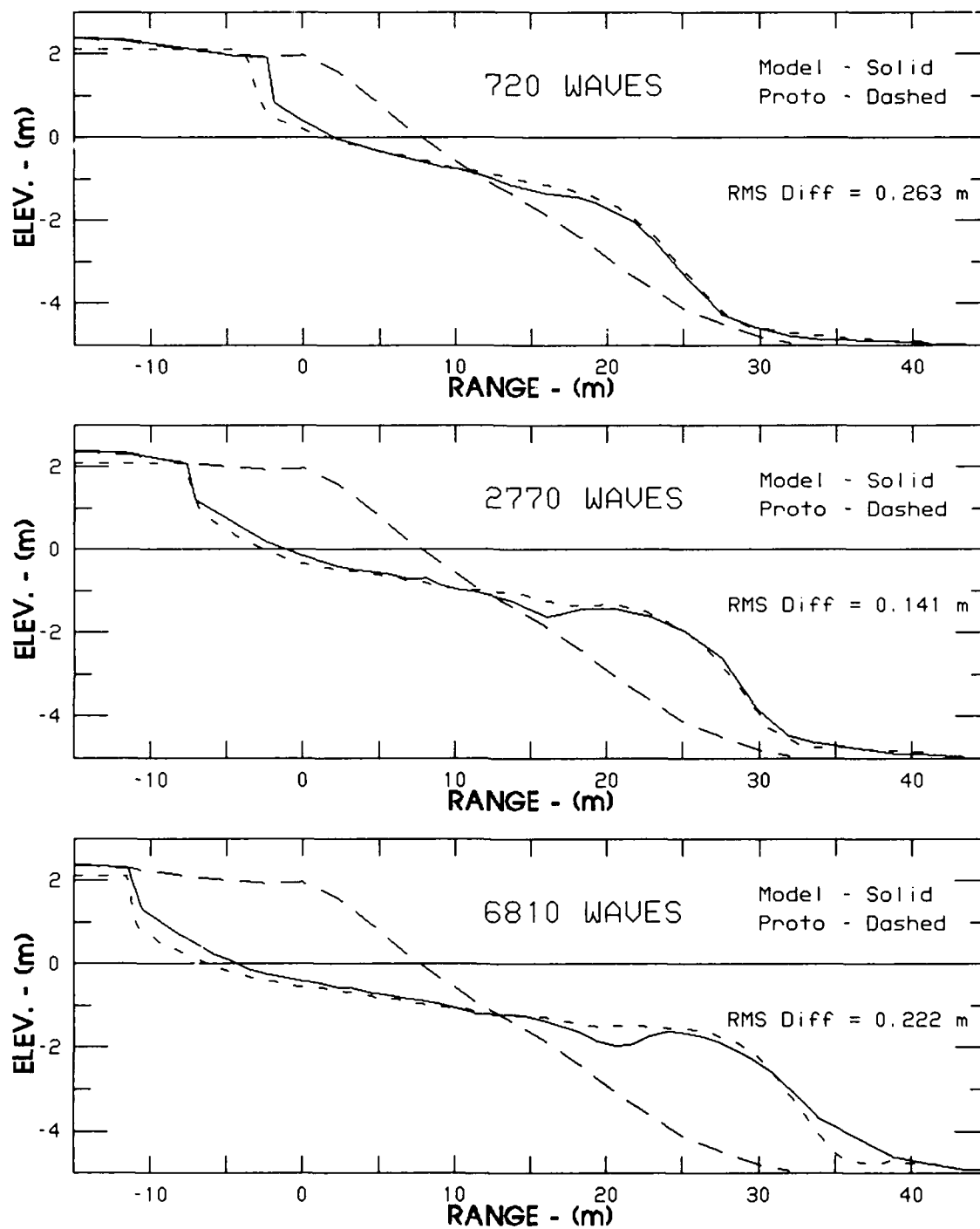


Figure 16. Profile-model comparison for test T14

131. When regular wave conditions in the model were increased 10 percent, better profile reproduction was observed with increased movement of nearshore sediment to the offshore region of the model. An explanation for this behavior was found by examining the ratio of the Xie parameter between prototype and model. Model test T04, with wave height increased 10 percent, showed better similarity of Xie's parameter in the offshore region than did test T03, as shown in Table 4. This supports the contention that the offshore bar has a *sediment capacity* for a given regular wave condition, and it suggests that the scaled wave height determined by application of the movable-bed modeling criteria given by Equation 6 should be augmented for uniform regular waves so that closer similarity between prototype and model values of Xie's parameter is achieved.

132. Verification of the scaling guidance under irregular wave conditions was highly successful (test T14). Profile development in the model closely followed that of the prototype-scale experiment and did not require altering the model significant wave height to provide closer correspondence to the Xie parameter. Based on these results, it appears that the irregularity of the wave train extends the region of sediment transport dominated by turbulence and hence moves the sediment farther offshore before transitioning into a bed-load-dominated mode.

133. Experimental repeatability was shown to be quite satisfactory at midscale under regular wave conditions, and overall, the verification of movable-bed scaling guidance based on undistorted Froude models preserving the sediment fall speed parameter has been achieved for the specific case of turbulence-induced profile development of regions characterized by noncohesive sediments. However, bear in mind that these results are encouraging to the extent that prototype-scale wave tanks can reproduce natural beach response without adverse laboratory effects.

## PART V: REGULAR WAVE PERTURBATION TESTS

### Increased Wave Height

134. The effect of a 10-percent increase in wave height in the movable-bed physical model was previously discussed in Part IV in conjunction with the observed improvement in the prototype-to-model comparison for regular waves. This observation resulted in a suggested adjustment to the previously presented scaling criteria when regular waves are used in the model.

135. Representative model-to-model comparisons, where the only difference between the compared tests was increased wave height, are shown on Figure 17 at equivalent stages of profile development. Comparisons are plotted in model units and have not been scaled to prototype dimensions. In these plots, the baseline case (profiles shown dashed) is test T03, and test T04 (profiles shown solid) is the case where the monochromatic wave height was increased by 10 percent. Wave height statistics and profile listings are given in Appendices B and C, respectively. Complete profile comparisons are presented in Figure E9 in Appendix E.

136. Increasing the wave height by 10 percent resulted in a 10-percent increase in wave steepness,  $H/L$ , at the position of the nearshore wave gage. The 10-percent factor may have varied as the wave underwent additional shoaling, but the wave steepness remained greater for test T04 up to the point of wave breaking. The increased wave height in the physical model resulted in an increased offshore movement of sediment due to the greater bottom water velocities under the steeper waves. A corresponding adjustment in the nearshore region was also observed as sediment was transported seaward. The larger regular wave heights also resulted in greater wave runup and more scouring of the berm after an equivalent number of waves. It is not known if the observed difference in the surf zone after 1,650 waves was due to the different *sediment demand* of the offshore bar or to the *sediment deficit* in the nearshore region resulting from the presence of the revetment.

### Decreased Wave Period

137. Test T07 was designed to be the same as the base test T03 except that the regular wave period was decreased by 10 percent from the wave period used in test T03. This decreased wave period resulted in shorter wavelength, which in turn increased the wave steepness,  $H/L$ , in test T07 over that of test T03. In the shallow-water limit, where wavelength is proportional to wave period, a 10-percent decrease in wave

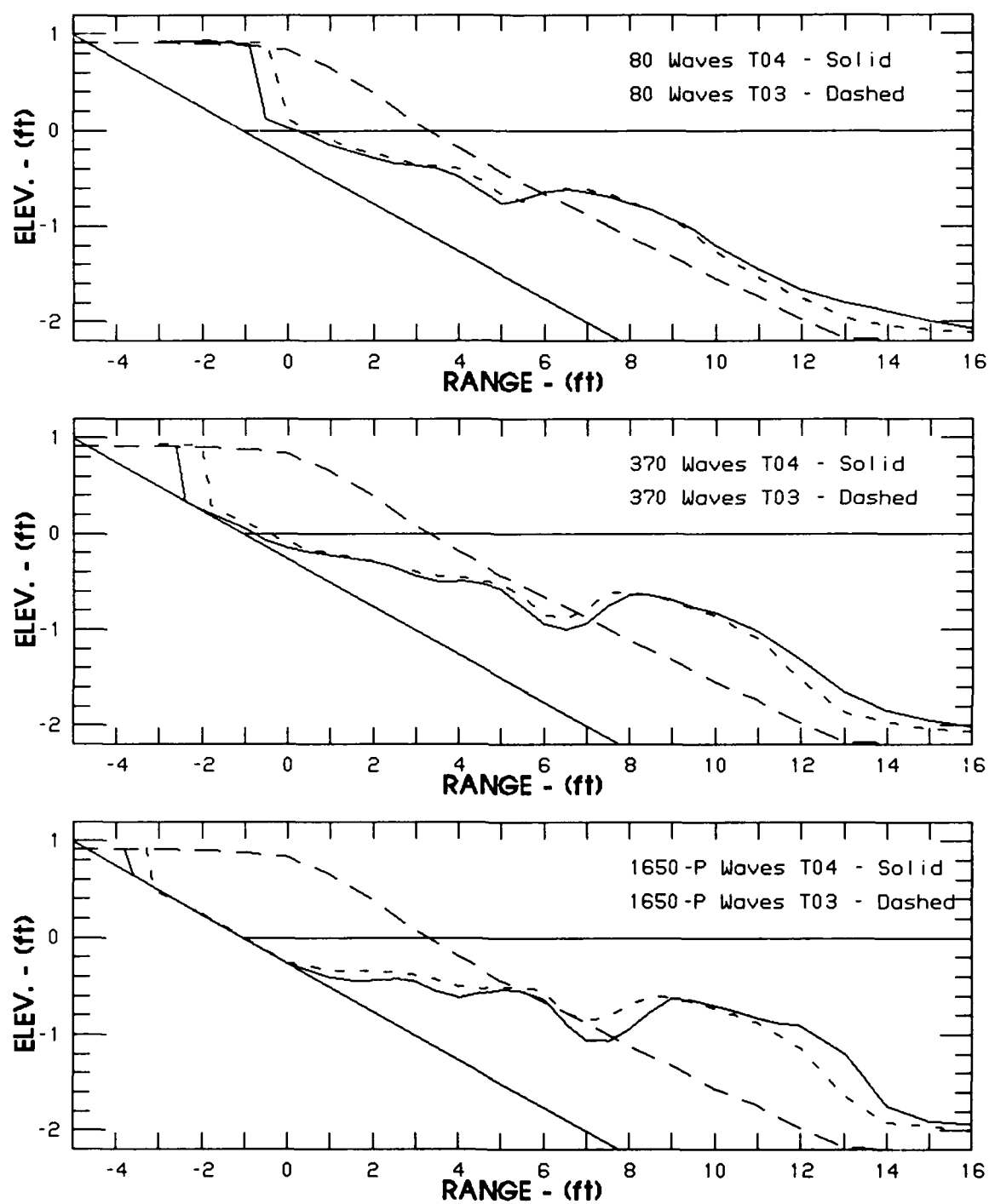


Figure 17. Wave height perturbation, T04 versus T03



period gives nearly the same wave steepness as a 10-percent increase in wave height. However, at the depth of the nearshore wave gage, the water depth is transitional, and the corresponding increase in wave steepness was calculated (linear theory) to be about 14 percent.

138. Representative model-to-model comparisons between tests T03 and T07 are shown on Figure 18 in model dimensions, and a complete set of profile comparisons is given in Figure E10 in Appendix E. Other results are given in the appropriate appendices. Differences between the base case (dashed line) and the test with decreased wave period (solid line) are not very apparent in the plots for 80 waves and 370 waves. There was slightly more scouring of the berm along with evidence of greater offshore transport, but not as much as in the case of increased wave heights. It was not until later in the experiment that differences became more evident (see Figure 18 at 1,650 waves).

139. As the test approached the equilibrium condition, case T07 exhibited greater movement of sediment offshore and substantially more scouring in the bar-trough region. This was due primarily to a change in the breaking wave dynamics brought about by the decreased wave period. It is also possible that backwash from the wave runup on the impermeable slope influenced the wave breaking kinematics. Generally, the differences in model profiles are similar to that observed for the perturbation of wave height. This is not unexpected in light of the induced increase in wave steepness, and the similarities are examined further in the following section.

## Equal $H/wT$ Parameters

140. The perturbation tests of wave height and wave period were designed so that test T04 (wave heights increased 10 percent) and test T07 (wave period reduced 10 percent) had nearly equal values of the fall speed parameter. The purpose in doing so was to compare the resulting profile evolution and to assess the relative importance of the fall speed parameter and the Froude scaling of the hydrodynamics. In essence, this comparison represents the situation where the fall speed parameter was held constant in an undistorted model, and the hydrodynamics were distorted from one case to the other to maintain  $H/wT$  similarity.

141. Representative comparisons between tests T04 and T07 are shown in Figure 19 with complete comparisons given in Figure E11 in Appendix E. Visually, a good correspondence is seen between the profiles on Figure 19, and it appears that a better match was obtained than in the two cases where the fall speed parameter was increased by 10 percent and compared with the base-case profiles (see comparisons in Figures 17 and 18). Table 6 presents the RMS variation between profiles as calculated by Equation 13. The top half of Table 6 lists the results in model dimensions, and the bottom half gives the same results scaled to equivalent prototype dimensions.

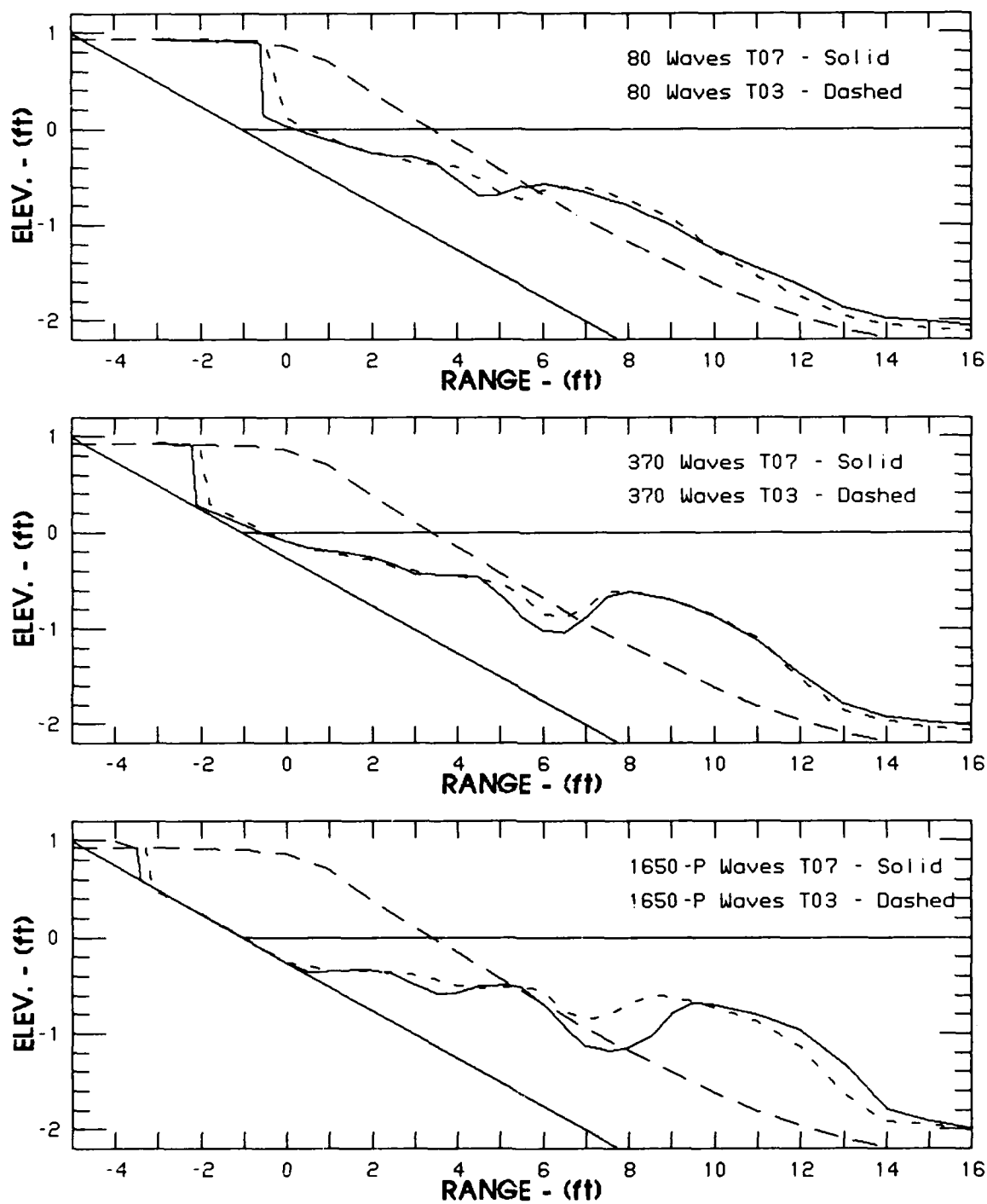


Figure 18. Wave period perturbation, T07 versus T03

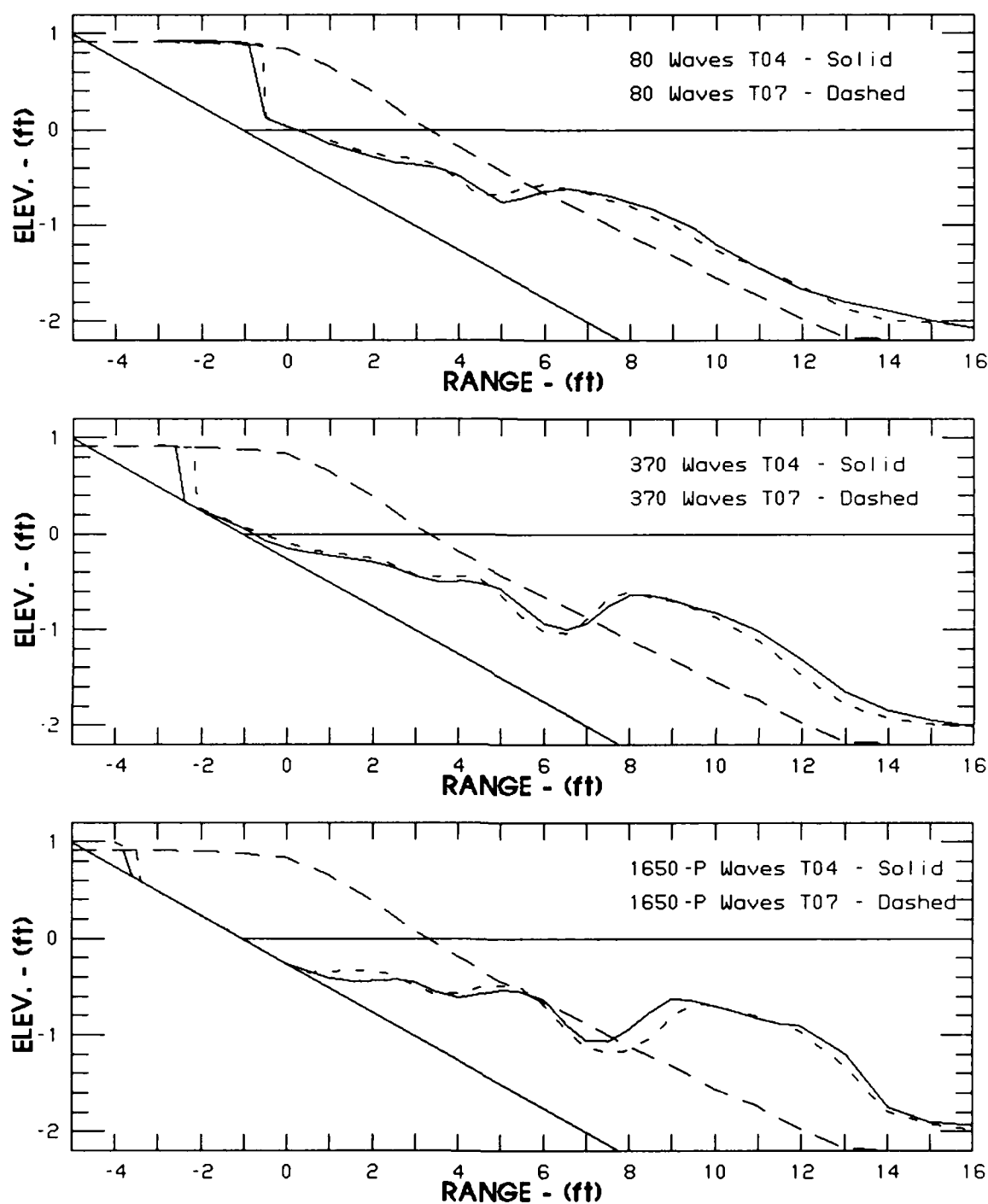


Figure 19. Equal  $H/wT$  parameters, T04 versus T07

142. Notice that the RMS variations calculated for the equal  $H/wT$  comparisons are in the same range as those values obtained for experimental repeatability (Table 5), whereas in the two cases when there was a 10-percent variation in fall speed parameters, the RMS variations are nearly twice as large.

143. Clearly, the tests with equal values of  $H/wT$  exhibit good agreement and support the importance of maintaining similar values of the fall speed parameter for this type of movable-bed modeling. However, this correspondence was demonstrated only for small perturbations in the wave parameters used to express the fall speed parameter. At some point, larger variations of the wave parameters to achieve similarity of fall speed parameter will undoubtedly affect the hydrodynamics to the extent that satisfactory similitude of profile evolution will not be achieved. As previously mentioned, tests T04 and T07 had similar values of  $H/L$ , and it should be expected that similar profile response would be observed.

Table 6. Wave Perturbation RMS Variations

Model Dimensions (feet)			
Case	80 Waves	370 Waves	1650 Waves
Increased Wave Height (T03 vs T04)	0.15	0.18	0.14
Decreased Wave Period (T03 vs T07)	0.16	0.13	0.18
Equal $H/wT$ Parameters (T04 vs T07)	0.05	0.11	0.09
Prototype Dimensions (meters)			
Case	80 Waves	370 Waves	1650 Waves
Increased Wave Height (T03 vs T04)	0.35	0.40	0.33
Decreased Wave Period (T03 vs T07)	0.36	0.30	0.41
Equal $H/wT$ Parameters (T04 vs T07)	0.12	0.26	0.21

144. The Froude criterion for scaling hydrodynamics is apparently still the best approach; however, the results (Table 6) suggest that the experimenter may have some latitude in applying the Froude scaling guidance and still achieve reasonable modeling results.

## Sediment Grain Size

145. All tests conducted as part of this test series used the same sand for the model movable-bed sediment; therefore, no direct tests involving perturbation of the sediment fall speed value were performed. However, it is possible to qualify the impact of different grain sizes in the model by examining similar model experiments conducted by Schulz (1985).

146. Schulz (1985) conducted movable-bed model simulations aimed at reproducing the same GWK prototype regular wave experiment as described in Part III of this report. Schulz's experiments were conducted at an undistorted length scale of 1:10 with hydrodynamics scaled according to the Froude criterion. Tests were conducted using three different grain sizes (0.18, 0.35, and 0.70 mm) to simulate the prototype grain size of 0.33 mm.

147. Figures 20 and 21 give intermediate and equilibrium comparisons of Schultz's 0.18-mm and 0.35-mm sand tests with the prototype condition. In both figures, the solid line is the model result scaled to prototype dimensions, and the dashed line is the prototype. For intermediate comparisons, the number of waves is different because profiling was performed at times different from in the prototype; hence, the closest profiles in terms of number of waves were chosen for comparison. The bottom plot on each figure represents the equilibrium condition, which occurred much later in the scaled model than in the prototype.

148. Neither the 0.18-mm nor the 0.35-mm grain size achieved a good match for the prototype profile evolution. The test compared in Figure 21 represents the use of model sediment nearly the same size as the prototype, which would be much coarser than what would be recommended using the scaling guidance presented in this report. The test compared in Figure 20 used a finer sediment than the prototype, but one that was still coarser than the scaling guidance would recommend.

149. At the 1:10 scale used by Schulz, the fall speed parameter scaling guidance (Equation 6) gives  $N_w = 3.16$  and would require a model sediment fall speed of 1.4 cm/sec to correspond to the prototype sediment (see Table 1). Model sand having a median diameter of about 0.12 mm would be required to adhere to the fall speed parameter scaling criteria with length scale equal to 1:10. Sand finer than the 0.18 mm used in Schulz's experiment (Figure 20) would be mobilized easier and could move toward the offshore region under the generated wave conditions.

150. Qualitatively, it can be concluded that large perturbations in the model sediment fall speed parameter due to grain size can greatly influence the movable-bed response. Similar conclusions cannot be made regarding the effects of small perturbations in grain size. It may be that perturbations in the sediment fall speed resulting from variations in water temperature or mean grain size may also contribute to the overall experimental error (see Part IV).

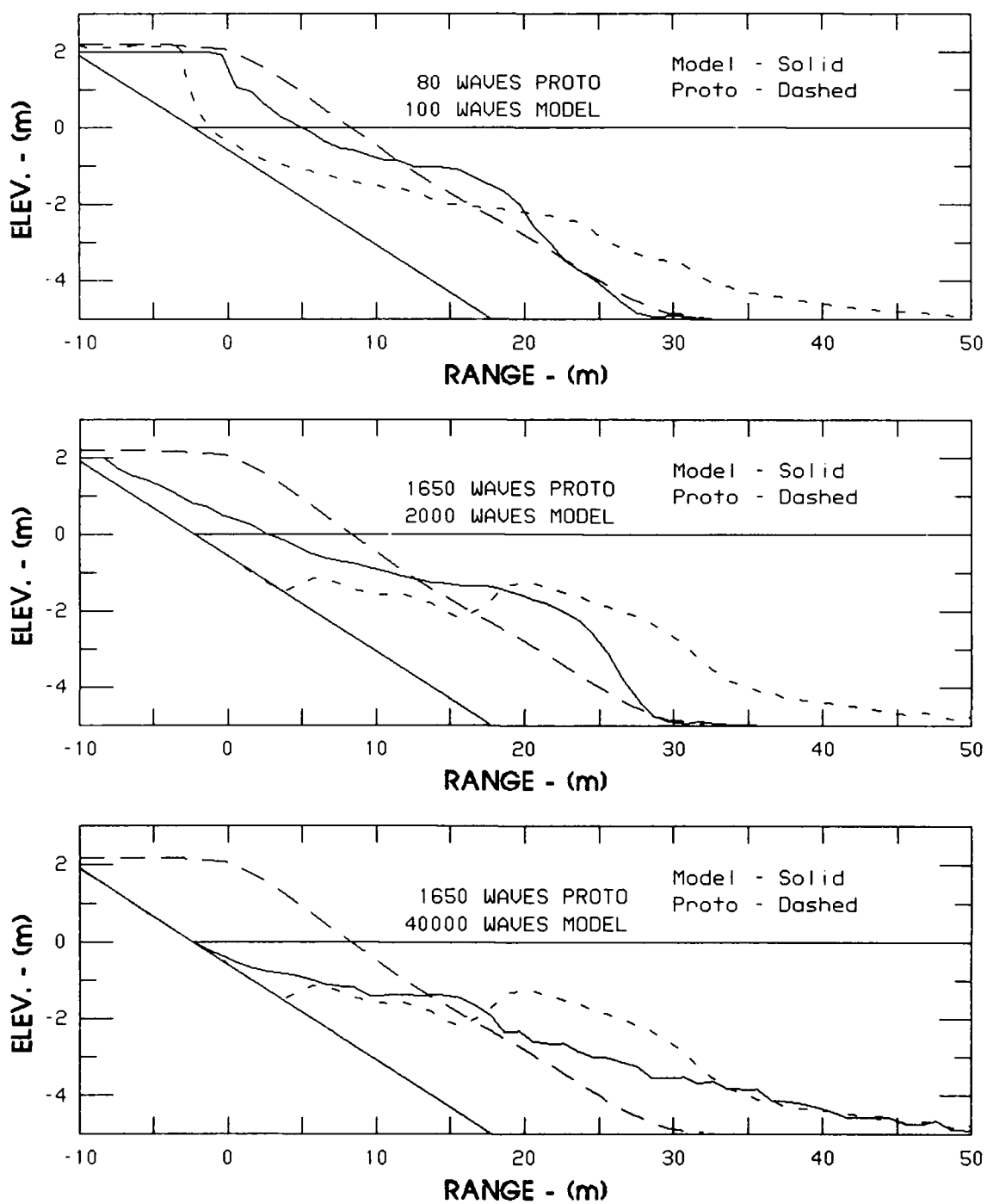


Figure 20. Schulz's (1985) experiment using 0.18-mm sand

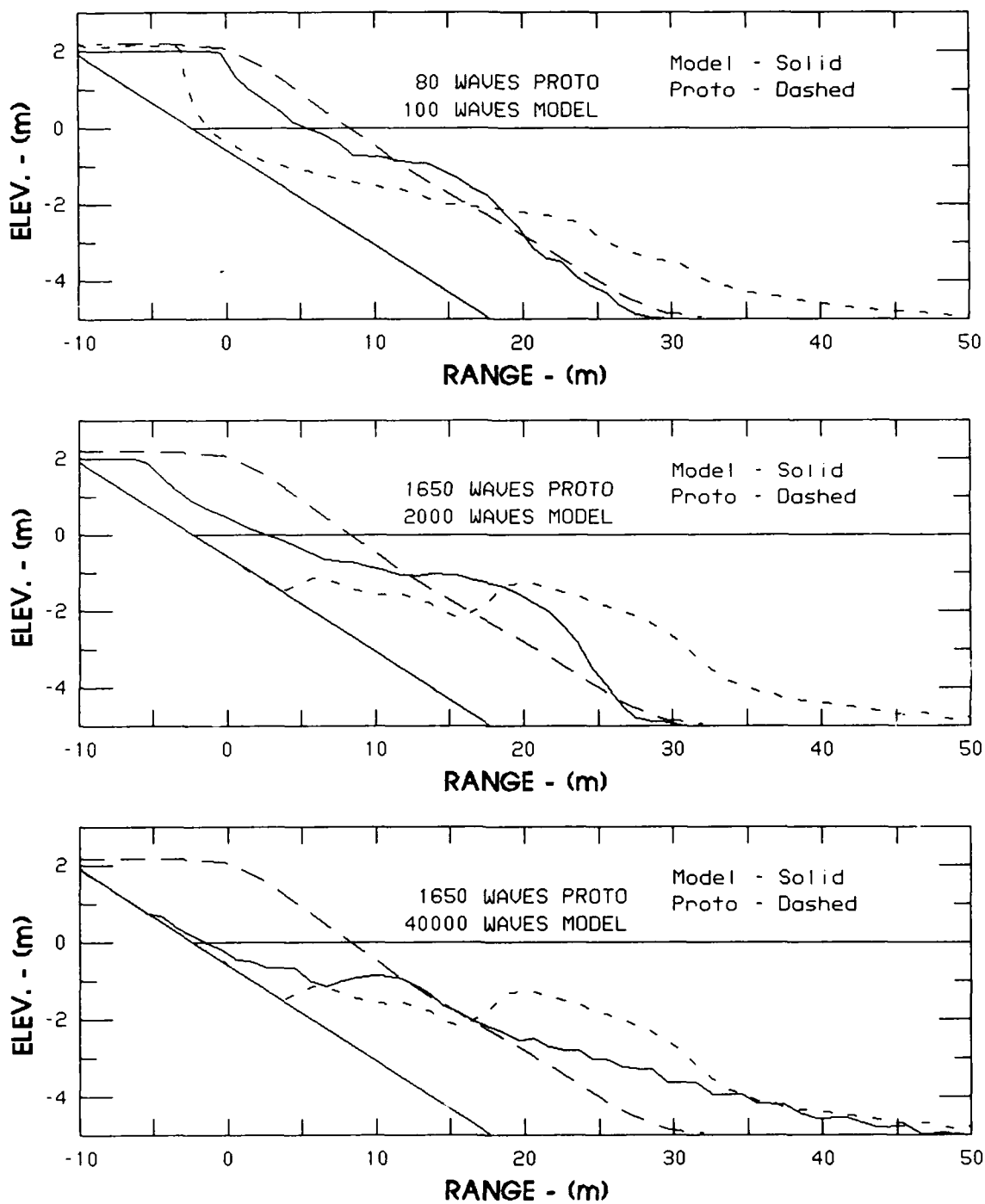


Figure 21. Schulz's (1985) experiment using 0.35-mm sand

## Initial Profile

151. Test T06 was conducted to examine the importance of initial profile on the equilibrium profile and the attempt to reproduce the prototype event. During the base test, T03, a substantial erosional difference was noted between the prototype and model profiles after 40 waves (see Figure 10). Because the difference in profiles is quite significant after a relatively short time into the test, it was thought that part of the prototype profile possibly had evolved as a result of massive slumping during the early portion of the experiment. If this was the case, this type of behavior would not be in similitude in the scaled model because it occurs in a regime controlled more by pore pressure than the fall speed parameter.

152. The prototype profile measured after 40 waves was molded into the wave tank to serve as the initial profile for test T06. The test was then conducted in the same manner as test T03. Figure 22 presents representative prototype-to-model comparisons of the temporal profile development. A complete set of profile comparisons is given in Figure E5 in Appendix E. Other relevant data pertaining to test T06 can be found in the appropriate appendices.

153. After 170 waves (the test was initiated at the 40-wave point) the prototype-to-model comparison seems to be quite good; however, after 370 waves, not as much sediment was being deposited in the offshore region as was observed in the prototype. This is more apparent after 1,650 waves, where a distinct difference is seen between the model and prototype profiles.

154. Figure 23 shows comparisons between tests T03 and T06 at selected surveying stops. Appendix E (Figure E12) contains the complete set of comparisons. Initially, the two profiles are quite dissimilar due to the different starting condition at 40 waves. Note in particular the difference in berm erosion. However, the two profiles soon started to match more closely as equilibrium was approached, and at the 1,650-wave profile, very little difference was observed.

155. Placing the 40-wave prototype profile in the wave tank as the initial profile improved the model-to-prototype comparisons for the short-term profile development (several hundred waves), but the resulting profile at the near equilibrium condition was very similar to that of test T03, indicating that this variation had little effect on the ultimate outcome of the experiment.

156. Uliczka and Dette (1988) discuss prototype-scale movable-bed tests where the only difference was a significantly different initial profile. Comparisons between tests indicated substantial differences in profile development due to the different profile slopes. Gourlay (1980) discusses the differences arising from varying the initial profile and also provides several references that give differing opinions.

157. In designing movable-bed models, it is wise to approximate the initial condition profile, particularly in the offshore portions, which may affect wave shoaling. However, the results from this test indicate that a certain degree of profile variation in the nearshore portion of the initial profile is permissible without unduly impacting the final outcome of the experiment.



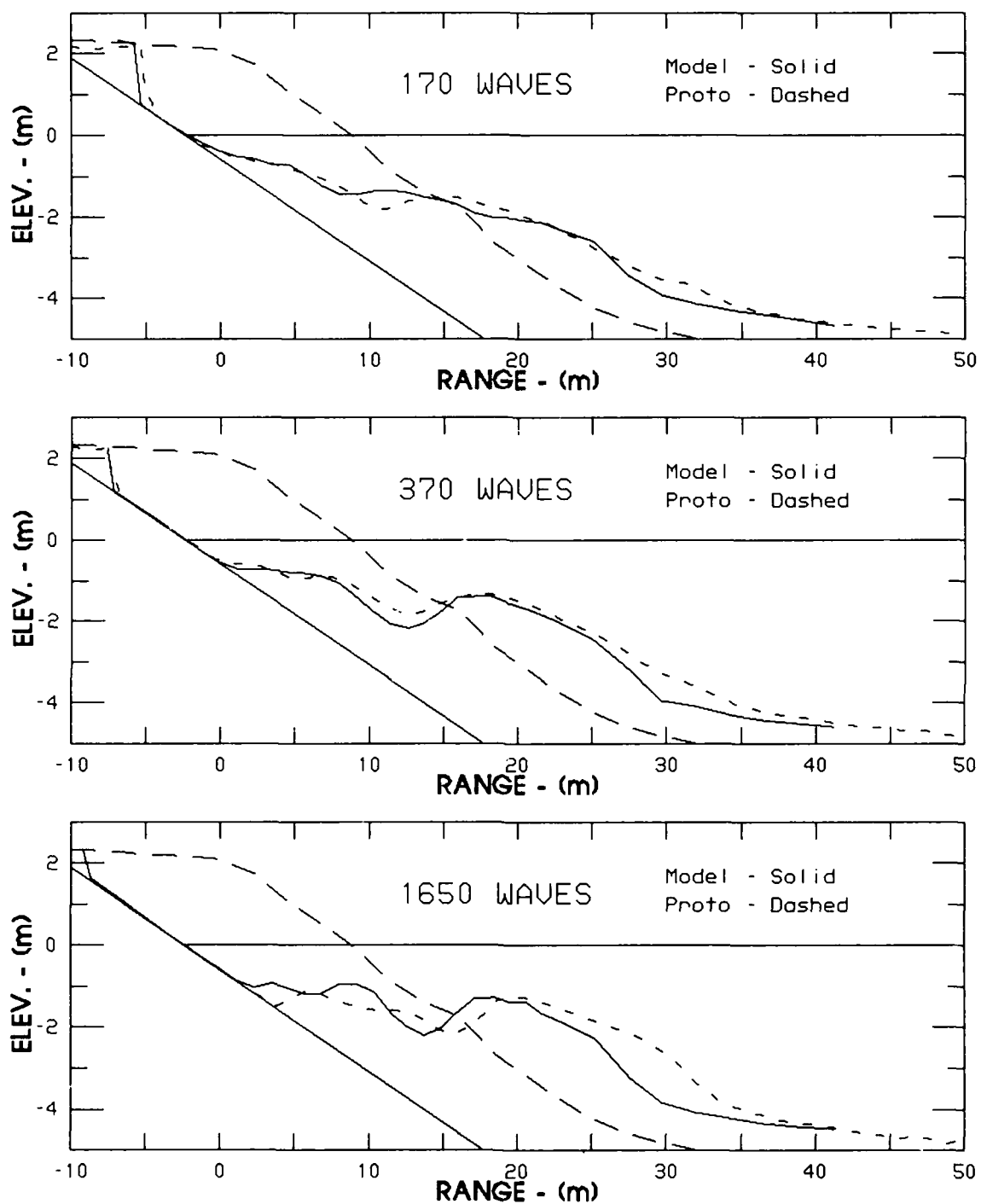


Figure 22. Prototype-model comparison, initial profile at 40 waves, T06

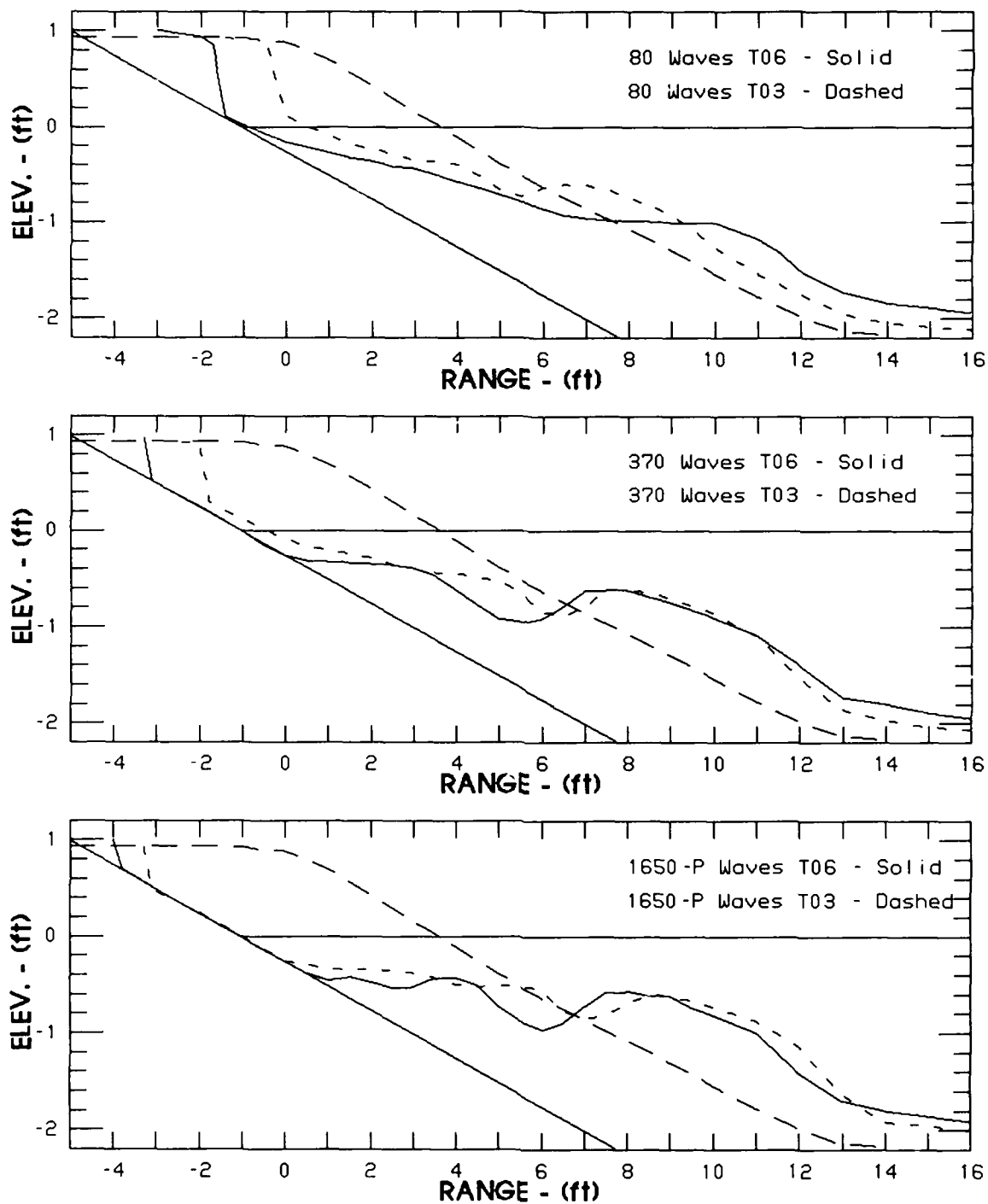


Figure 23. Initial profile at 40 waves, T06 versus T03

## Decreased Sediment Supply

158. The impact of decreased sediment supply available to the profile can be examined by comparing tests T01 and T03. As previously mentioned, tests T01 and T02 were conducted with approximately 10-percent less sediment in the berm than the equivalent prototype conditions. Therefore, test T01 represents the case where there was less sediment available for redistribution across the equilibrium profile.

159. Figure 24 shows representative comparisons between tests T01 and T03, while the complete set of comparison plots is given in Figure E13 in Appendix E. The solid line is the test with 10-percent less sediment, and the dashed line is the base test T03. There was not much difference between the two tests other than the reduced sediment profiles appear to be slightly lower because less sediment was available for depositing over the profile.

160. If the offshore bar indeed has a *sediment demand* under given wave conditions, then it would be expected that the comparisons would show the same offshore bar configuration with the nearshore profile being scoured more deeply for the reduced sediment case. The comparisons shown in Figure 24 are inconclusive in this respect because the observed variation in the offshore profile was not significant enough to disprove this hypothesis. Other tests where sediment was withheld from the profile by placement of a vertical seawall are discussed in Part VII of this report.

## Absorbing Wave Board

161. Waves reflected from the beach and sloping revetment in the movable-bed experiments necessitated stopping the wave machine after about 80 waves so that re-reflected waves from the wave board did not adversely affect the experiment. This was the same procedure followed in the German GWK prototype tests. Test T05 was conducted with a wave-absorbing capability activated on the wave board in the 6-ft wave tank. This was the first time this feature had been used in laboratory tests since installation.

162. The absorbing board has three wave gages spaced across on the face of the board that sense and average the water level. This averaged value is compared with the specified value of water level that should be present without any reflected wave energy, and any difference is compensated by the appropriate increase or decrease of board stroke. Present equipment limitations require that a lower frequency cutoff be employed to avoid damage to the hydraulic components. This means that reflected waves with frequencies below the cutoff frequency cannot be absorbed.

163. Figure 25 compares test T06 (solid line), where waves ran continuously between profiling stops, with base test T03, where stops occurred after 80 waves to allow the reflections to settle. As evidenced by

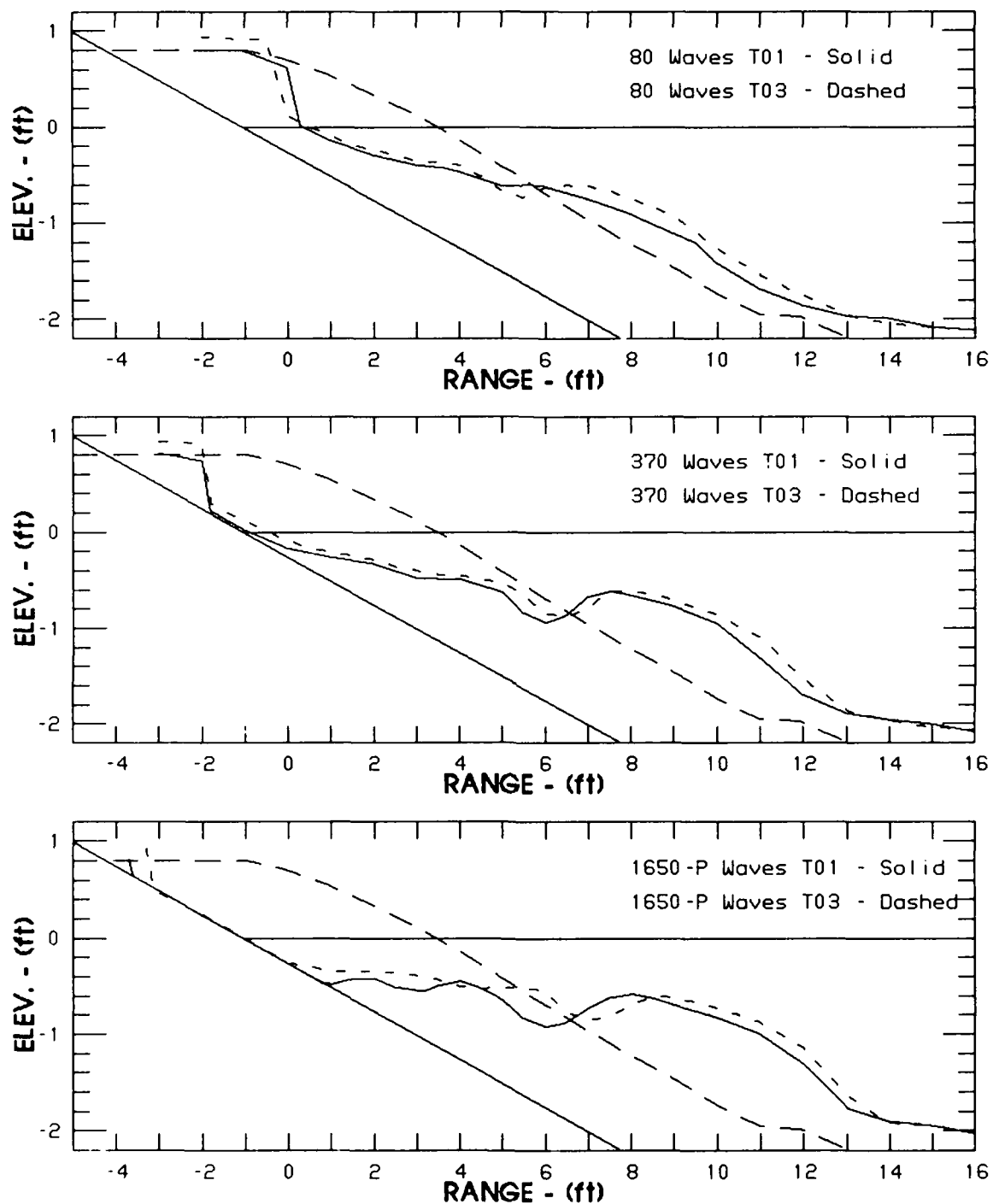


Figure 24. Reduced sediment comparison, T01 versus T03

the figure, the absorbing wave board produced a significantly different response from the standard method of stopping wave generation more frequently. The profiles formed by the absorbing wave board exhibit smoother features and substantially more movement of sediment to the deeper portions of the profile. In addition, berm erosion was more pronounced during the intermediate stages of profile development when wave absorption was being performed.

164. Examination of the wave records from the absorbing board test reveals that the system correctly removed the reflected waves at the incident frequency, but the procedure produced a spurious long wave at a frequency below the cutoff frequency. Thus, the incident waves attacked the profile while the short-term mean water level was oscillating up and down. When the water level was elevated, more of the berm was susceptible to erosion, and when the water level was depressed, the waves moved more sediment into deeper water. During the test, it was observed that the break bar feature was migrating back and forth due to the low-frequency oscillation in the flume.

165. This first test of the absorbing wave board indicated that it will probably be necessary to use this capability in conjunction with spurious long wave suppression techniques when attempting to generate monochromatic waves with active absorption.

## Summary of Perturbation Tests

166. Movable-bed physical model tests designed to examine the effects of parameters thought to be important in reproducing prototype-scale behavior were conducted in the 6-ft wave tank. Increasing the height of the regular waves promoted further offshore movement of sediment and a corresponding adjustment of the surf zone profile. Similar behavior was observed when the wave period was decreased by 10 percent. This similarity is probably related to both perturbations resulting in similar increased values of wave steepness.

167. The importance of preserving the fall speed parameter was confirmed by comparing tests where the hydrodynamics were varied from the Froude criterion in order to maintain equal values of  $H/wT$  between experiments. Although good results were obtained in this instance, it is still recommended that the Froude criterion be adhered to, as well as maintaining the same value of fall speed parameter.

168. Grain size perturbation was examined using previous results of Schulz (1985). Qualitatively, the behavior was consistent with the established scaling criteria, at least for the case of the undistorted scale model.

169. Differences in initial profile did not substantially affect the ultimate outcome at near-equilibrium; however, short-term differences were expected and were observed. For reproducing prototype-scale events, it was concluded that accurate reproduction of the offshore profile is desirable, whereas accurate details of

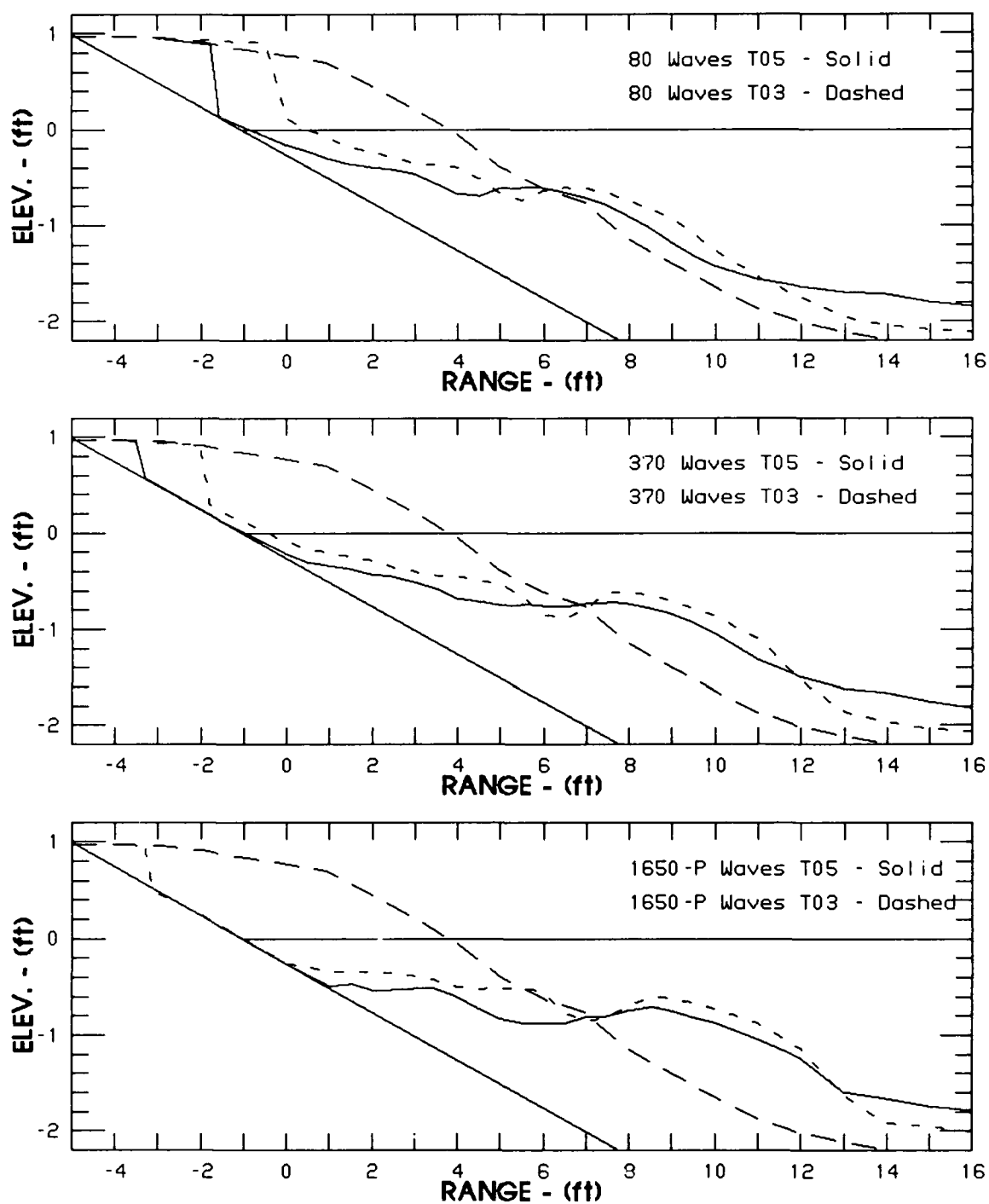


Figure 25. Absorbing wave board test, T05 versus T03

the initial surf zone profile are of secondary importance.

170. Comparisons between tests with differing amounts of available sediment were inconclusive because the observed differences were of similar magnitude to differences arising from experiment repeatability.

## PART VI: IRREGULAR WAVE TESTS

171. This section of the report examines profile evolution caused by irregular waves and compares the results with corresponding regular wave cases. All of the irregular wave tests were conducted with the sloping revetment as illustrated in Figure 6.

### Background

172. Much of the established design guidance for sediment transport has been derived in part from laboratory tests conducted with movable-bed models using uniform, regular wave trains. For engineering design based on this guidance, the irregular wave condition which exists in nature is commonly represented by a single statistical wave height parameter that is taken as being equivalent to the regular wave height in the design formulae.

173. With the advent of irregular wave-generating capabilities in the laboratory, the means are available to systematically examine differences between regular and irregular waves and their effects on the process being modeled. The objective of such studies is to determine which irregular wave parameter best matches the regular wave parameter used to establish the design guidance. This is most important for projects that are constrained to using design criteria developed from regular-wave tests. Eventually, older design criteria will be superseded by new criteria developed from field data and/or laboratory tests incorporating irregular waves.

174. Shallow-water, irregular waves typically can be represented either by a statistical wave height parameter or by an energy-based parameter. Statistical wave height parameters are averages of the time series of waves taken over time whereas the wave process is assumed stationary. Typical parameters include mean wave height (average of all waves),  $H_{rms}$  (RMS square wave height), and  $H_{1/3}$  (average of highest 1/3 waves). The primary energy-based wave height is  $H_{mo}$ , which is directly related to the energy contained in the wave spectrum and approximately equal to  $H_{1/3}$  under the narrow-banded Gaussian assumption.

175. Although  $H_{mo}$  and  $H_{1/3}$  are approximately equivalent in deep water, the two parameters can be distinctly different as the waves shoal (Thompson and Vincent 1984, 1985; Hughes and Borgman 1987). Therefore, in selecting an irregular wave parameter to provide equivalence to regular waves, it will be necessary to determine whether a statistical parameter or an energy-based parameter is more appropriate.



## Previous Efforts

176. Only recently have researchers begun using laboratory facilities to examine differences between regular and irregular waves on beach profile development. Consequently, studies documenting the differences are limited.

177. Mimura, Otsuka, and Watanabe (1986) conducted a series of small-scale, movable-bed model tests using irregular waves. The test flume was partitioned down the center line, and a fine-grained sand (0.18 mm) was used on one side while a coarse-grained sand (0.75 mm) was used on the other side. Initial beach slopes of 1:10 and 1:20 were tested, and irregular wave tests were conducted to cover the range of previous tests performed using regular waves.

178. Mimura, Otsuka, and Watanabe examined several different aspects of sediment transport to determine the most appropriate irregular wave parameter for each case. As a result of their tests, they concluded that the mean wave height of irregular waves gave best correspondence to regular waves when used to predict whether the profiles were either eroding or accreting. The prediction technique they used was formulated with a coefficient based on regular wave tests. They further concluded that use of  $H_{1/3}$  in the formula required modification of the coefficient.

179. Threshold of sediment movement under irregular waves was found by Mimura, Otsuka, and Watanabe to be better represented in existing prediction expressions by  $H_{1/3}$  than by the mean wave height. They based their conclusion on experimental determination of critical depth for motion under irregular waves compared with a formulation previously determined for regular wave tests. They stated that this finding is logical because the sand grains are more responsive to the larger waves in the wave field.

180. Profile evolution in the Mimura, Otsuka, and Watanabe tests was observed to be much slower for the irregular wave case, and this was thought to be the result of both erosive and accretive wave conditions being present in the irregular wave train. A representative wave parameter could not be specified for sediment transport rate because both the mean wave and the significant wave height ( $H_{1/3}$ ) produced similar results.

181. Recently, success has been reported in efforts to numerically simulate profile response due to cross-shore sediment transport (Larson 1988, Larson and Kraus 1989). The numerical model of Larson and Kraus (1989) incorporates several empirical formulations obtained from analysis of prototype-scale wave tank experiments conducted with regular waves. Application of the model to field situations requires specification of representative statistical wave heights. In simulations of documented field erosional events, they found that the numerical model produced better results when the energy-based  $H_{m0}$  was used as the equivalent wave height. Use of the average wave height as the irregular wave parameter did not perform as well because an insufficient quantity of sediment was moved during the simulation. Their simulations of field events provide a link between the proper representative irregular wave statistic and the equivalent

regular wave height used to develop the empirical basis of the numerical model.

182. Larson and Kraus (1989) also developed a predictor for delineating erosive and accretive conditions by assembling both prototype-scale and small-scale regular-wave laboratory data. In application of the criterion to a collection of field observations, they found that the mean wave height of the field data provided best correspondence to the regular-wave laboratory results. This further supports the conclusions of Mimura, Otsuka, and Watanabe (1986).

183. Uliczka and Dette (1987) compared profiles from regular and irregular wave tests in the prototype-scale GWK wave tank. Each test began with a plane beach installed on a 1:4 slope with median grain size of 0.33 mm. Regular wave heights of 1.5 m at periods of 6 sec were run intermittently in bursts of up to 80 waves until an equilibrium was established. The irregular waves were generated with significant height ( $H_{1/3}$ ) equal to 1.5 m and peak spectral period of 6 sec; these conditions were run for intervals totaling nearly 12 min until little change occurred between subsequent profiles.

184. Uliczka and Dette (1987) reported the regular wave case reached an equilibrium state much faster than the irregular wave case (4,000 waves as opposed to about 7,000 waves), and the total eroded volume of sediment was approximately 20 percent greater for the regular wave case. They also observed that sediment was not transported as far offshore in the irregular wave case, and the profile was smoother and did not produce a breakpoint bar under irregular wave action. The lack of a bar feature was attributed to the range of depths over which the irregular waves were breaking. Although the irregular wave condition eroded approximately 20-percent less sediment, note that the irregular waves contained approximately 30-percent less total energy than did the regular wave case.

185. The remainder of this section discusses the results obtained from tests conducted as part of the present study.

## **Irregular $H_{1/3}$ Equal to Monochromatic Wave Height**

186. Prior to placing the sand in the 6-ft wave tank, the wave machine was calibrated to produce an irregular significant wave height at the nearshore gage location equal to the regular wave height of the base case T03. Test T09 was conducted using this calibrated condition. The water depth at the nearshore gage was sufficiently deep so that the measured statistical significant wave height was approximately equal to the energy-based parameter  $H_{mo}$ .

187. Subsequent analysis of water surface elevation data collected at the nearshore wave gages showed values of the irregular wave statistic,  $H_{1/3}$ , slightly higher than the target height of 0.66 ft (see Table B9 in Appendix B). The increase over the nearshore gage values measured during low-reflection calibration tests is attributed to wave reflection that increased the nonlinear aspects of the wave forms.

188. Beginning with the usual plane-sloping beach, irregular waves were run in the physical model for approximately the same time spans as the regular wave experiments, with stops in between to allow water motions in the tank to settle and to survey the intermediate profiles. At the stopping points of the experiment, long-period seiching motions, with largest amplitudes estimated visually to be about 5 to 7 cm, were present in the wave tank. Suppression of spurious long-wave motions in the wave tank was not implemented at the time of the test; therefore, it is not possible to determine how much of the long-wave energy was associated with spurious long waves and how much could be attributed to reflection of the naturally occurring bound long wave of the irregular wave train. Nevertheless, long-period motions were allowed to subside before continuation of the test.

189. Figure 26 compares representative profiles from irregular test T09 with the corresponding profiles from the base test T03 after approximately the same number of waves (equal elapsed time of wave action). The complete set of comparisons is given in Figure E15 in Appendix E, profiles showing the evolution of test T09 profile are given in Figure D9 in Appendix D, and wave analysis results and profile soundings are in Appendices B and C (Tables B9 and C9), respectively.

190. Generally, the irregular wave condition (solid line) produced similar erosional history as the regular wave case (dashed line), but at a slower rate. The initial adjustment of the plane-sloping berm occurred over about the same time span in both cases (regular and irregular waves). After the initial adjustment, evolution of the profile under irregular wave action was less than in the regular wave case, with the most noticeable region of difference being the berm recession. This observation follows the same trend as reported by Mimura, Otsuka, and Watanabe (1986) and Uliczka and Dette (1987). The irregular wave-induced profile reached a near-equilibrium state at the 1,650 wave-profiling stop (see comparative profiles in Figure D9 in Appendix D), which corresponds to the same response of the profile under regular wave action.

191. Comparison of the regular and irregular wave profiles after 1,650 waves shows a close correspondence between profiles, indicating that the regular wave condition was well matched by the irregular wave condition where  $H_{1/3}$  equals the monochromatic wave height. Cross-tank variation in the profile after 1,850 waves was minimal compared with that observed in the regular wave case. (See center-line profile 1850-P versus sidewall profiles 1850-G and 1850-C for test T09 in Appendix D.) It is presumed that the irregularity of the wave field helped to subdue whatever mechanism was responsible for the cross-tank variations in the regular wave tests.

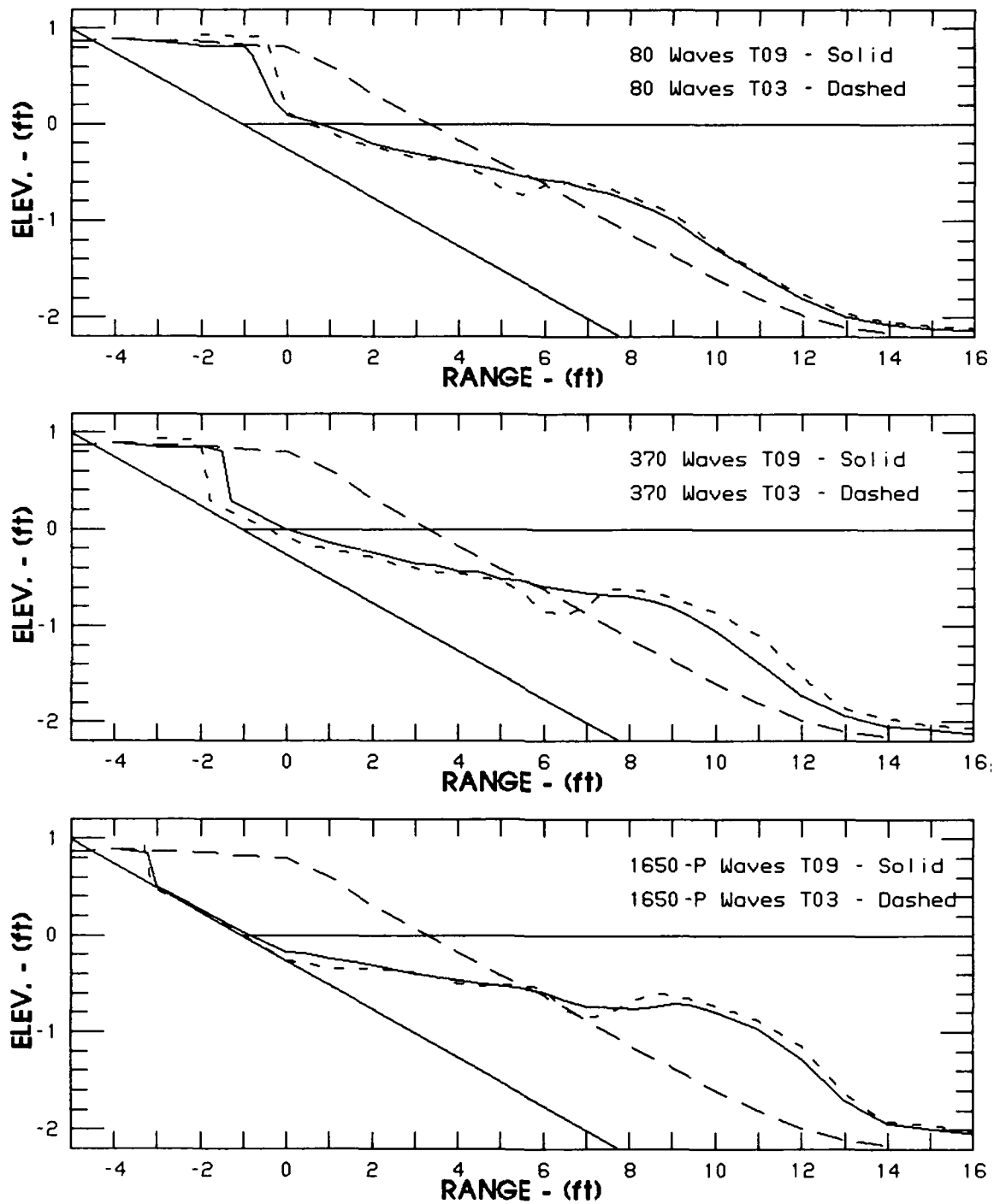


Figure 26. Irregular wave comparison,  $H_{1/3}$  equals  $H_{mono}$  ( $H_{mono}$  = monochromatic wave height)

## Irregular Wave Energy Equal to Monochromatic Wave Energy

192. Test T08 was conducted with an irregular significant wave height of  $H_{1/3}$  equal to 1.4 times the monochromatic wave height used in base case T03. This provided approximately the same spectral wave energy to the profile as present in the regular wave case, and under the Rayleigh assumption for wave height distribution, corresponded to  $H_{rms}$  of the irregular waves being equal to the monochromatic wave height. The purpose of this test was to examine whether equivalent energy levels are necessary to obtain similar profile development between model regular and irregular wave physical model tests.

193. It was originally thought the target significant wave height of 1.4 times the monochromatic wave height had not been achieved in the flume. This condition had not been previously calibrated, and analysis of the nearshore wave gage array (see Table B8 in Appendix B) made it appear as if the measured significant wave height was too low. To further clarify the situation, the wave machine was calibrated during the September 1989 series to produce the correct wave condition, and test T12 was run to duplicate test T08. Wave measurement analyses and profile response were nearly identical for both T08 and T12. This confirmed that test T08 represented the desired 41-percent increase in significant wave height, but that reflected waves acted in some manner to decrease the nearshore wave heights as when compared with the nonreflective calibration condition. Even so, the important aspect to remember is that the total wave energy in the flume had been increased by 41 percent.

194. Results from T12 are not documented in this report because they were essentially the same as test T08. Test T12, however, did provide another example of experimental repeatability, and the comparison is included as Figure E18.

195. Comparisons between the irregular wave test T08 and the base regular wave case T03 revealed a substantially different profile response to the increased wave energy. Figure 27 compares irregular wave test T08 (solid line) with regular wave test T03 (dashed line) at various profiling stops. Additional comparisons are given in Figure E16 in Appendix E.

196. The increase in wave energy resulted in greater erosion of the berm area and also resulted in movement of the sediment farther offshore than in the regular wave case. The comparison after 1,650 waves also reveals a significantly different profile in the region of wave breaking and seaward of breaking. Visual comparison between the results shown on Figures 26 and 27 clearly indicates that better correspondence between regular and irregular wave tests was achieved if the significant wave height was made equal to the monochromatic wave height. The relative differences between the two irregular wave tests are illustrated on Figure 28 where the more energetic case is shown by the dashed line. (Also see full comparisons in Figure E17 in Appendix E.)

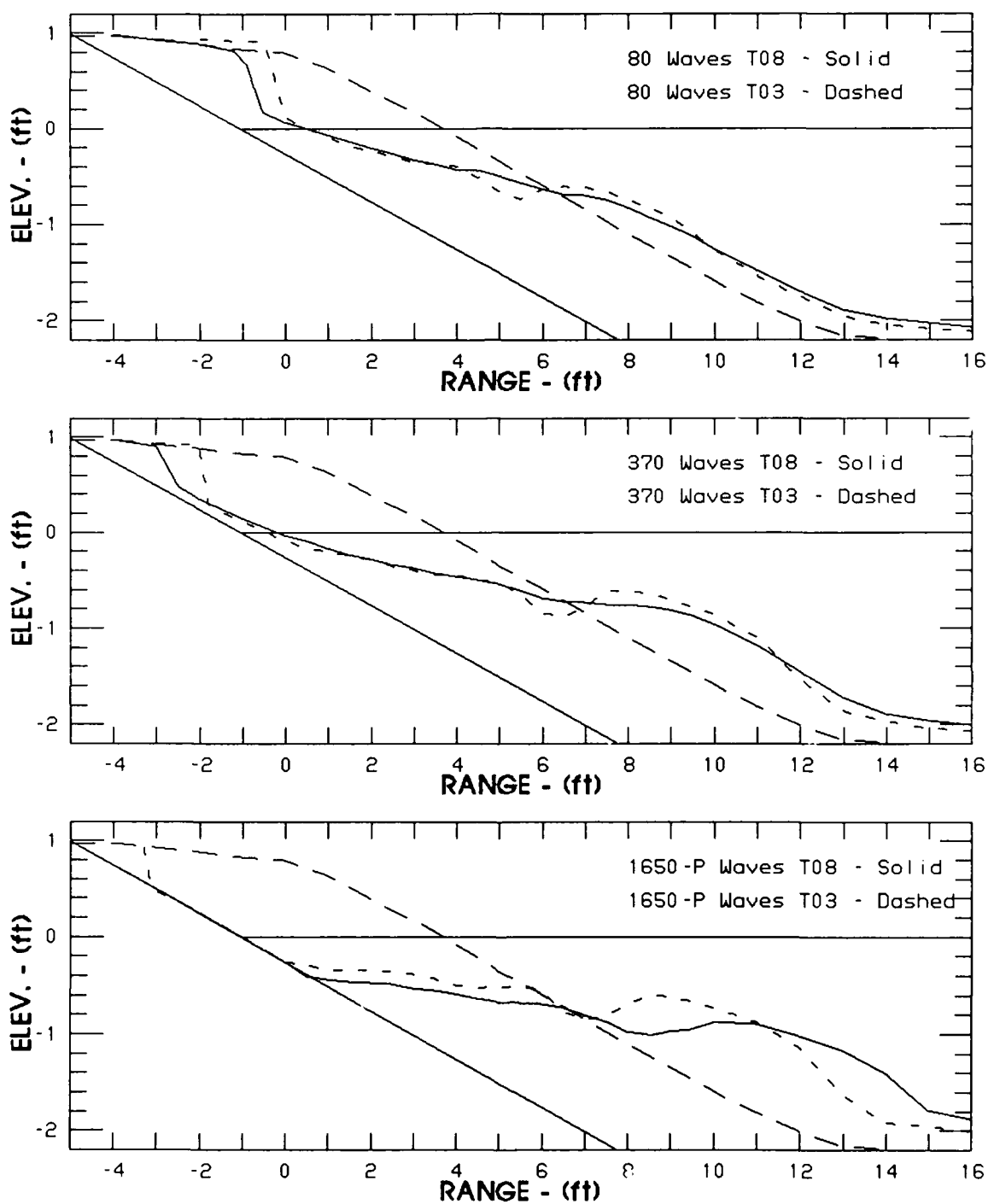


Figure 27. Irregular wave comparison,  $H_{1/3}$  equals 141 percent  $H_{mono}$

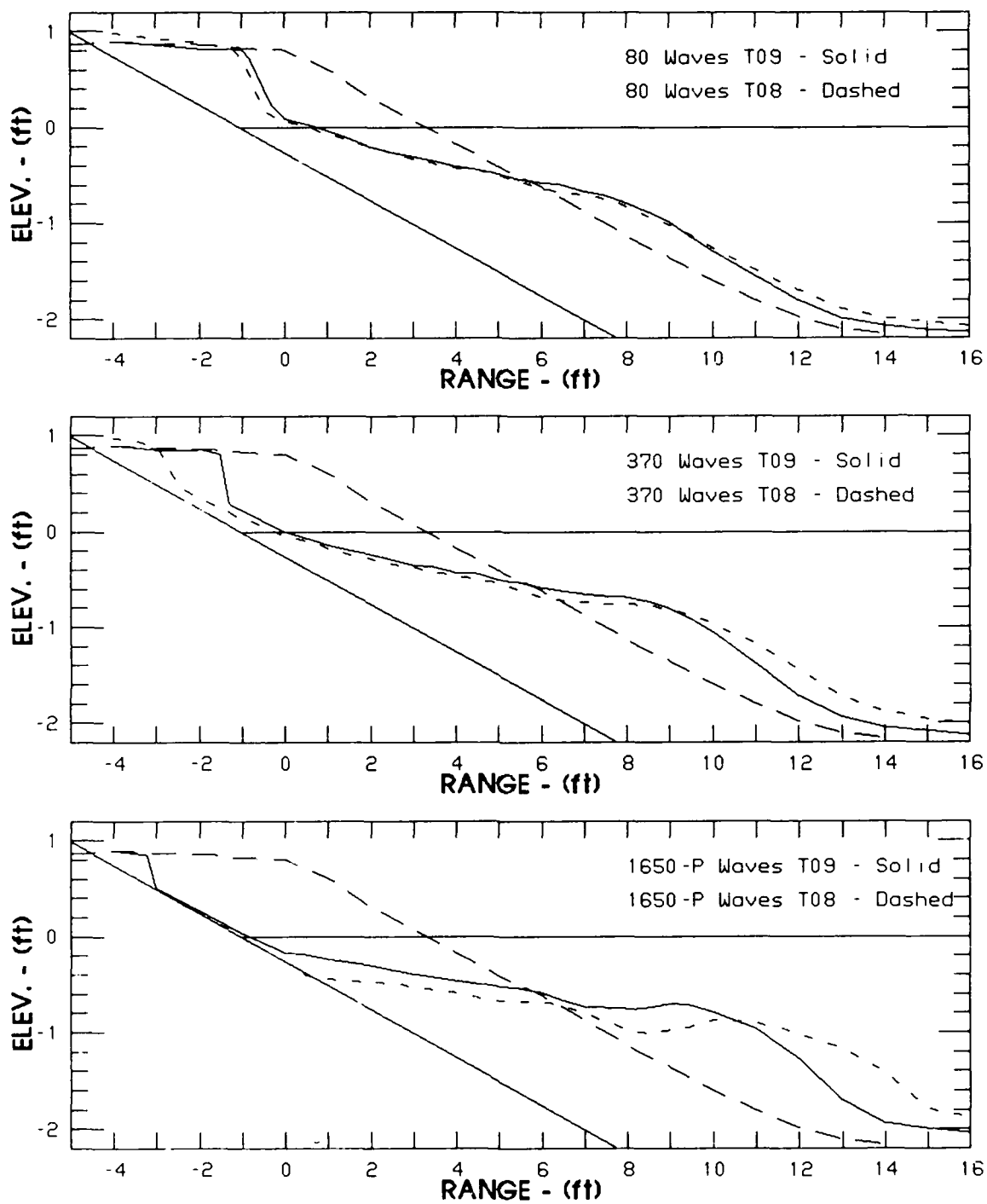


Figure 28. Irregular wave perturbation, T09 versus T08

## Discussion of Irregular Wave Tests

197. Movable-bed model tests using irregular wave conditions showed better success at reproducing regular wave results when the significant wave height ( $H_{1/3}$ ) of the irregular waves had nearly the same value as the monochromatic wave height. This was well demonstrated by the comparison shown in Figure 26. Increasing the energy level of the irregular waves by 41 percent resulted in excessive erosion relative to the base case T03 (Figure 27).

198. Although irregular waves with significant wave height equal to the regular wave height contain approximately 30-percent less total energy than their regular wave counterpart, the two conditions are similar in terms of the waves that move the sediment. In the irregular wave case, the waves in the distribution larger than the significant wave height are expected to move more sediment than what would be moved by waves in the monochromatic case, whereas waves in the distribution less than the significant height should move less sediment than in the monochromatic case. Irregular waves much smaller than the regular wave height might be expected to have minor effects on the sediment transport.

199. The fact that significant wave height emerged as a good parameter for reproducing observed regular-wave tests indicates that the higher 1/3 waves in the distribution are the most important for sediment transport. Experiments conducted with equivalent energy levels ( $H_{1/3}$  is 1.4 times greater than  $H_{mono}$ ) contain a proportionally higher number of waves greater than the monochromatic wave height and, thus, should cause significantly more erosion of the nearshore profile. Therefore, it is believed that *maintaining equivalent energy levels between regular and irregular waves is not proper guidance for the situation of beach profile development due to cross-shore sediment transport.*

200. For purposes of analysis, assume for the moment that the only waves in the irregular wave height distribution that contribute to net sediment transport are confined to the highest 1/3 waves; waves with lower heights are present, but have no appreciable effect. Under this assumption, it might be expected that profile development in the irregular wave case should take approximately three times as long as the regular wave counterpart. Three times as many irregular waves would need to impinge on the beach to produce the number of irregular waves in the highest-1/3 category equal to the number of regular waves required for the same profile development. However, it is quite unreasonable to assume that all waves smaller than the highest 1/3 waves make no contribution whatsoever to sediment transport. It is more likely that profile development under regular waves is somewhere between one to three times more rapid than the irregular wave case with some smaller waves actually having an accretionary effect as discussed by Mimura, Otsuka, and Watanabe (1986).

201. Figure 29 shows time-shifted comparisons between the irregular wave test T09 and its regular wave equivalent, test T03. In Figure 29, regular wave profiles (dashed) are compared with profiles that took approximately twice as long to develop in the irregular wave test (solid). Generally, a slightly better



correspondence is seen for 370, 750, and 1,450 waves (irregular waves) than is seen when the two conditions were compared after equal numbers of waves (see Figure 26 and other comparisons in Appendix E). However, the improved correspondence obtained by time-shifting the profiles is evident only after the first 300 waves. Prior to that point, profile comparisons are better when the morphological time scales were equal.

202. The observed trend for irregular-wave-induced profile evolution to take longer than corresponding profile development in the regular wave tests is the same as observed by Mimura, Otsuka, and Watanabe (1986) and Uliczka and Dette (1987). Qualitatively, the morphological time scale factor between irregular and regular wave profile response was about 2; i.e., profile development took twice as long under irregular waves. This rate is somewhat faster than indicated by the data published by Uliczka and Dette (1987).

203. The tests described by Uliczka and Dette (1987) did not expose the 1:4 sloping concrete revetment because the sand berm was sufficiently wide so as to preclude that possibility. During the tests in the 6-ft tank, equilibrium was reached rapidly in both the regular and irregular wave cases after the revetment was exposed. This rapid move toward equilibrium may have been caused by sediment no longer being available for offshore transport. This may partially explain the differences in profile evolution times noted between the present tests and those of Uliczka and Dette.

## Conclusions Regarding Irregular Waves

204. Movable-bed physical model tests conducted using irregular waves successfully reproduced profile development observed using regular waves. Best results were obtained when the significant wave height of the irregular waves was chosen as the equivalent parameter to the regular wave height. This equivalence was in a water depth sufficiently deep so that the Rayleigh distribution assumption was still valid, and measured  $H_{1/3}$  was approximately the same as measured  $H_{mo}$ .

205. Profile evolution under irregular waves was slower by approximately a factor of two, although there are no strong physical arguments to justify this factor other than observation. The slowing of erosion may be caused by some waves in the irregular wave train moving sediment onshore. Qualitatively, this follows the same trend observed by other investigators.

206. Exposure of the revetment and subsequent depletion of the available sediment for transport on the upper profile lead to rapid formation of the equilibrium profile in the irregular wave tests. This resulted in the irregular wave case reaching equilibrium after nearly the same elapsed time as the regular wave case. Absence of the revetment very likely would result in more lengthy profile development times for the irregular wave case, as noted in the experiments of Uliczka and Dette (1987), and this was demonstrated during the irregular wave verification tests when the revetment was not exposed (see Part IV of this report).

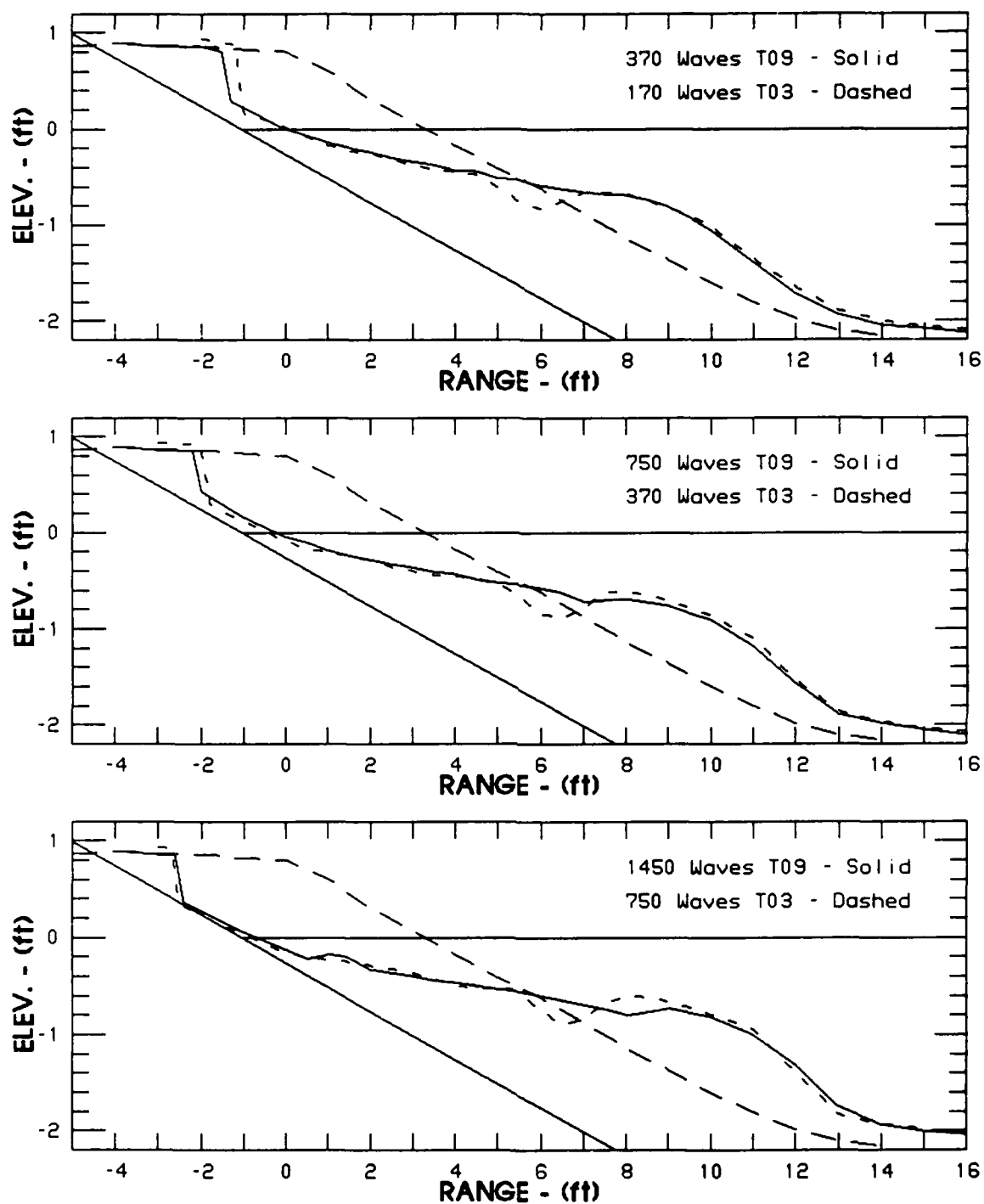


Figure 29. Time-shifted irregular wave comparison, T09 versus T03,  $H_{1/3}$  equals  $H_{mono}$

## PART VII: VERTICAL SEAWALL TESTS

### Background

207. Vertical seawalls placed on eroding beaches are designed to protect the land shoreward of the seawall location. Recently, seawalls have been cited as being either the cause of erosion to the beach fronting the seawall or contributing to increased rates of erosion to the beach profile (e.g., Pilkey and Wright 1988). This criticism and the projected rise in sea level will undoubtedly require engineers and coastal planners to make tough decisions on whether protection of upland investments warrants placement of structures such as seawalls. Because these decisions will be difficult, they ought to be based, to the maximum extent possible, on scientific facts and knowledge of the impacts of seawalls on fronting and adjacent beaches.

208. Opinions concerning the impact of seawalls on beaches are widely varied, mainly because insufficient scientific evidence is available to substantiate claims of the parties debating the issue. To date, the most comprehensive review and analysis of existing data and studies pertaining to seawall effects is that of Kraus (1988), which critically reviewed approximately 100 scientific papers related to seawall effects on the beach. The reader is referred to Kraus for his conclusions regarding seawall effects and additional details. (Note that Kraus (1988) appears in a volume dedicated to examining the effects of seawalls on beaches and the different viewpoints on the topic.)

209. One particular point addressed by Kraus (1988) was whether the volume of sand scoured locally on the profile in front of a seawall is greater or less than the volume eroded on adjacent beaches without seawalls. Expressed in another way, "Is the volume of sand being denied to the profile by the seawall similar to the volume of additional erosion observed in front of the seawall?" Kraus cites several field studies that indicate the volume of sediment withheld is approximately the same as the additional eroded volume over the profile of the seawalled beach. In one of the cited studies, Birkemeier (1980) used aerial photography to conclude that the eroded volumes of seawalled profiles and adjacent natural profiles were nearly the same. In another study, Kriebel (1987) reported that posthurricane field measurements on the Florida west coast indicated that the "... volume of sand lost due to scour at the seawall was approximately equal to the volume eroded on the adjacent beach without a seawall".

210. Dean (1986) presented logical arguments founded on the principle of sediment conservation in discussing the potential effects of coastal armoring on fronting and adjacent beaches. One of Dean's proposed "approximate principles" for the 2-D case was that the local volumetric scour in front of a coastal structure should be equal to or less than the volume that would have eroded if the structure had not been in place.

211. Barnett (1987) conducted 2-D laboratory tests using a movable-bed model scaled according to the criteria given by Equation 6. Tests were conducted using regular waves and sand with a median grain size of 0.15 mm. Profile measurements were made at 1/3 spacings across the wave tank and then averaged to compensate for the observed cross-tank variations. Erosive test cases without a seawall were compared with similar tests with a seawall located at different positions on the profile. Volumetric comparisons of the "final" profiles indicated that the eroded volume in front of the seawall was less than the corresponding erosion on the natural profile in 10 of the 11 comparisons. On average (as determined by linear regression), 61-percent less volumetric erosion occurred on the seawalled profiles. (Also see Barnett and Wang 1988).

## Impact of Seawall

212. The *approximate principle* that the amount of sediment denied the profile by the presence of a seawall is balanced by additional erosion in front of the seawall was tested in cases T10 and T11. The primary difference between these tests and previous tests conducted in the flume was the presence in the flume of a vertical seawall constructed of marine plywood. The seawall was positioned on the sloping revetment approximately at the intersection of the still-water line and revetment. The seawall was constructed such that it effectively prevented sediment behind it from eroding as the revetment became exposed due to wave action. The presence of the sloping concrete revetment and subsequent wave-induced exposure of the revetment make these tests somewhat unique in comparison with previous laboratory studies that examined seawall impacts.

## Regular Wave Comparisons

213. Profile development under regular wave conditions with and without the vertical seawall is compared in Figure 30 for three different stages of development. The complete set of comparisons is given in Figure E19 in Appendix E, and associated experiment documentation is presented in the appropriate appendices. In Figure 30, the solid-line profiles (test T10) represent the profile development with the vertical seawall in position, and the dashed-line profiles are from test T03 (no vertical seawall). After 80 waves, profile development between the two tests is quite similar because the vertical seawall had just become exposed during the last few waves, and its effect was negligible to this point. Note that the sloping revetment is still covered with sand at the 80-waves profile. Even after 370 waves had impacted the initial plane-sloping beach, little difference between the tests in the profile development seaward of the vertical seawall was observed. Gradually, however, differences between the two tests began to appear after

370 waves (see plots in Figure E19 in Appendix E). At 750 waves, the profile with the vertical seawall showed increased scouring of the surf zone and decreased height of the offshore bar feature. At the equilibrium condition (after 1,650 waves), quite distinct differences were observed between tests T03 and T10, although the time required to reach the equilibrium profile appeared to be very similar in both tests.

214. The 1,650-wave comparison in Figure 30 shows that the seawall promoted increased erosion of material from the surf zone and caused a decrease in the offshore bar height. The extra material eroded was used to satisfy the *sediment demand* in the region immediately seaward of the bar feature. The removal of sediment from the bar crest was probably due to a combination of increased breaking wave height as the incident wave interacted with the wave reflected off the vertical wall and offshore return flow patterns different from those generated in the absence of a vertical seawall. However, wave statistics presented in Tables B3 and B10 (Appendix B) indicated that measured waves and reflection coefficients at the nearshore gages were quite similar for both tests, suggesting that any increased reflection caused by the vertical wall was attenuated as the reflected wave returned through the surf zone.

215. Cross-tank variations in the profile occurred during test T10 as well as test T03. Figure 31 compares the final profiles at the glass sidewall (top), the center line (middle), and the concrete wall (bottom). The additional eroded area resulting from the seawall was calculated for all three profile comparisons; then an average was subsequently calculated to determine the eroded volume for comparison with the withheld volume. The withheld volume per unit width of the flume was about  $1.54 \text{ ft}^3/\text{ft}$ ; and the calculated average volume of additional erosion was  $1.58 \text{ ft}^3/\text{ft}$ , resulting in the eroded volume being only 3 percent greater. Eroded volumes per unit width for the individual profile comparisons were  $1.92 \text{ ft}^3/\text{ft}$  at the glass wall,  $2.13 \text{ ft}^3/\text{ft}$  on the center line, and  $0.68 \text{ ft}^3/\text{ft}$  at the concrete wall, resulting in the average of  $1.58 \text{ ft}^3/\text{ft}$ .

216. The near equivalence between the additional eroded volume in front of the seawall to the volume retained behind the seawall conforms to the field observations of earlier investigators, and it also follows the conclusions given by Dean (1986); however, the present result is substantially different from the average of laboratory results presented by Barnett (1987). The difference between the two may well lie in the fact that this is a single test result, whereas Barnett examined 11 different cases. Further tests are needed to examine a wider variety of vertical seawall conditions.

## Irregular Wave Comparisons

217. The irregular wave comparison consisted of running the same irregular waves used in test T09, but with the seawall installed on the sloping revetment as described above. Thus, the only difference influencing profile development between cases T09 and T11 was the presence of the seawall. Figure 32 shows comparison plots between vertical seawall test T11 (solid line) and non-seawalled test T09 (dashed

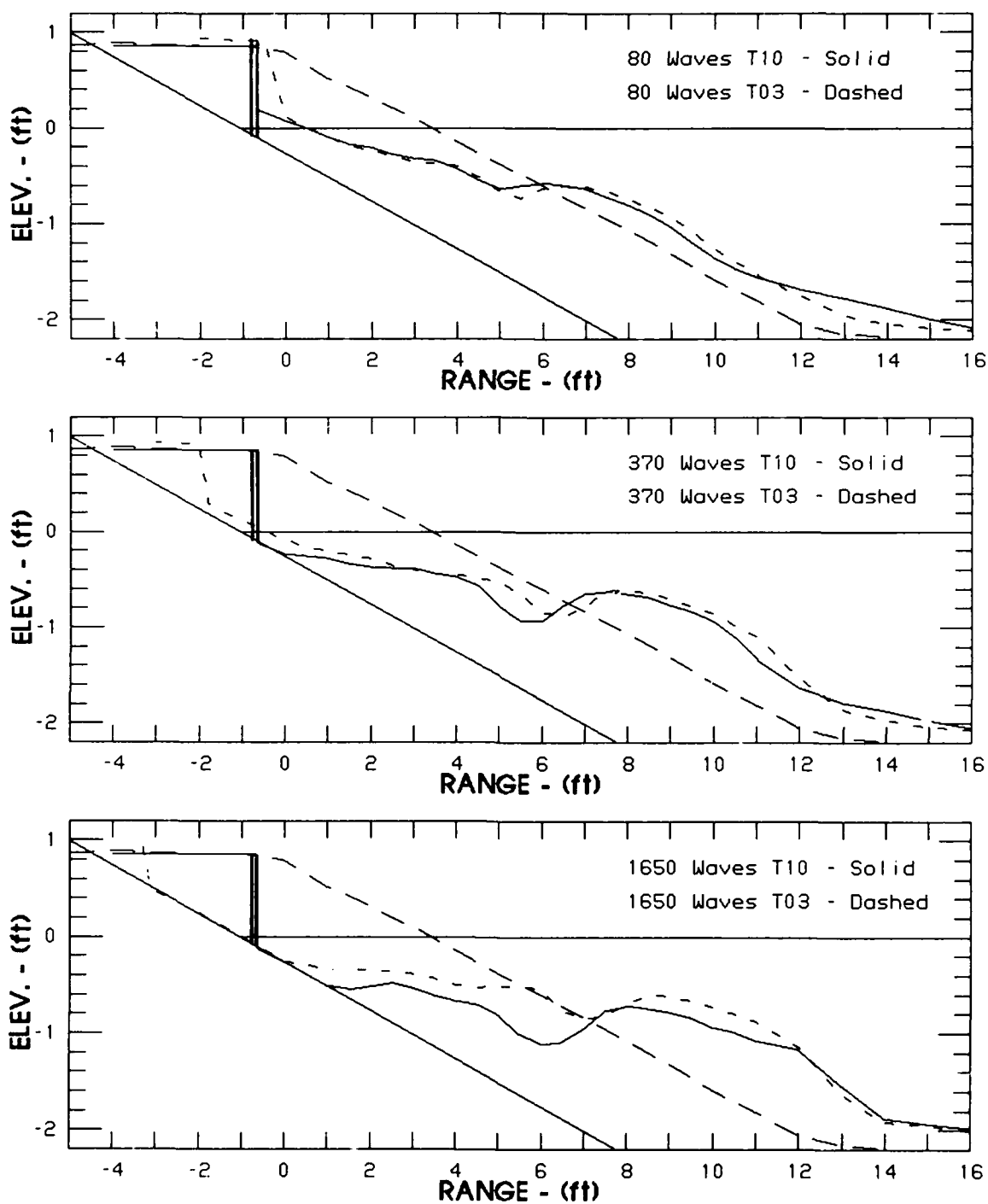


Figure 30. Seawall impact under regular waves, T10 versus T03

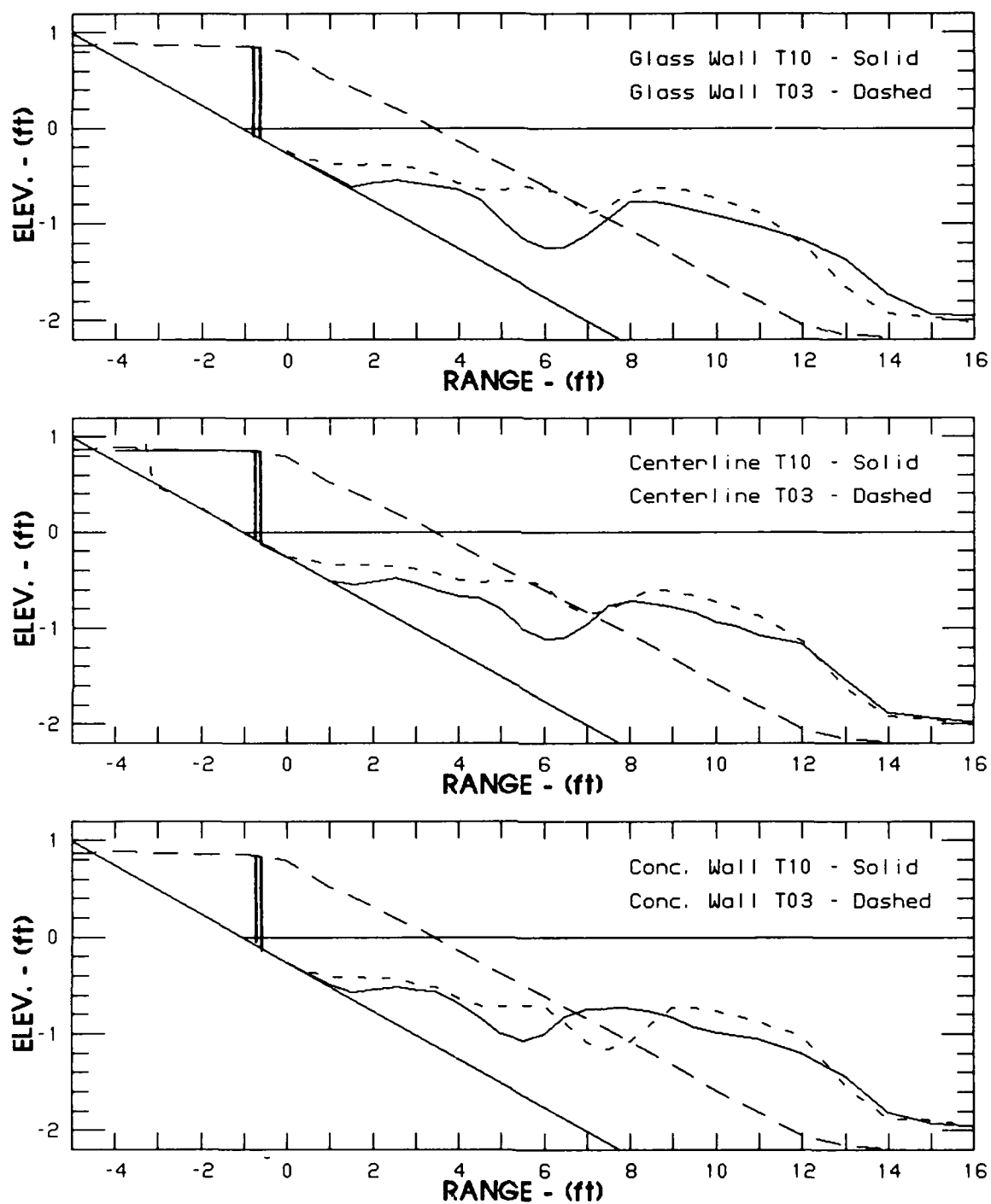


Figure 31. Seawall impact cross-tank variation, T10 versus T03

line) after approximately 80, 370, and 1,650 waves. Figure E20 in Appendix E contains the complete set of comparisons. Wave analyses, profile soundings, and profile plots for test T11 are given in Appendices B, C, and D, respectively.

218. The comparisons in Figure 32 were quite similar to the regular wave comparisons of T03 and T10. Initially, the profile development is very similar with little difference apparent between the two tests. Eventually, as the tests approached equilibrium, the seawall began to affect profile evolution with increased erosion in the surf zone region and removal of sediment across the crest and seaward slope of the slight bar feature as shown after 1,650 waves. Interestingly, there is a fairly uniform distribution of the additional erosion due to the vertical seawall, and the variety of waves in the irregular wave field helped to smooth the profile response. As in the regular wave case, no systematic differences in wave statistics or reflection coefficients were evident, and profile evolution also appeared to progress at similar rates.

219. As is typical in laboratory tests involving irregular waves, cross-tank variation in the profile was visually observed to be minor, although no sidewall profiles were obtained to document this observation for test T11. The additional eroded area on the center-line profile seaward of the seawall was calculated to be  $1.49 \text{ ft}^3/\text{ft}$  compared with the measured withheld sediment quantity of  $1.79 \text{ ft}^3/\text{ft}$ . Hence, the eroded volume for this case was about 83 percent of the withheld volume, a smaller percent than was obtained with regular waves, but still considerably higher than the average of 61 percent reported by Barnett (1987).

## Regular Versus Irregular Wave Effects

220. Test T11 with the vertical seawall in place represented the irregular wave counterpart of test T10 with  $H_{1/3}$  of the irregular wave train being nearly equal to the monochromatic wave height and the peak spectral period of the irregular waves equal to the period of the regular waves. Profile evolution for these two cases is compared in Figure 33 at 80, 370, and 1,650 waves. The complete set of comparisons is in Figure E21 in Appendix E.

221. Generally, the comparison is satisfactory throughout the profile development with the irregular wave condition (solid line) producing about  $0.53 \text{ ft}^3/\text{ft}$  less surf zone erosion after 1,650 waves and exhibiting a smoother shape, as was expected. This result agrees with earlier comparisons between regular and irregular waves presented in Part VI and further supports the conclusion that the irregular wave parameter  $H_{1/3}$  best represents the monochromatic wave height in the situation of profile development.

222. After the initial adjustment in the early stages of the experiment, time for profile evolution in the irregular case appeared to lag the regular wave profile development by a factor of approximately two. Figure 34 compares time-shifted profiles where the time for development in the irregular wave case is about twice as long as in the regular wave case. All time-shifted comparisons exhibit better correspondence than



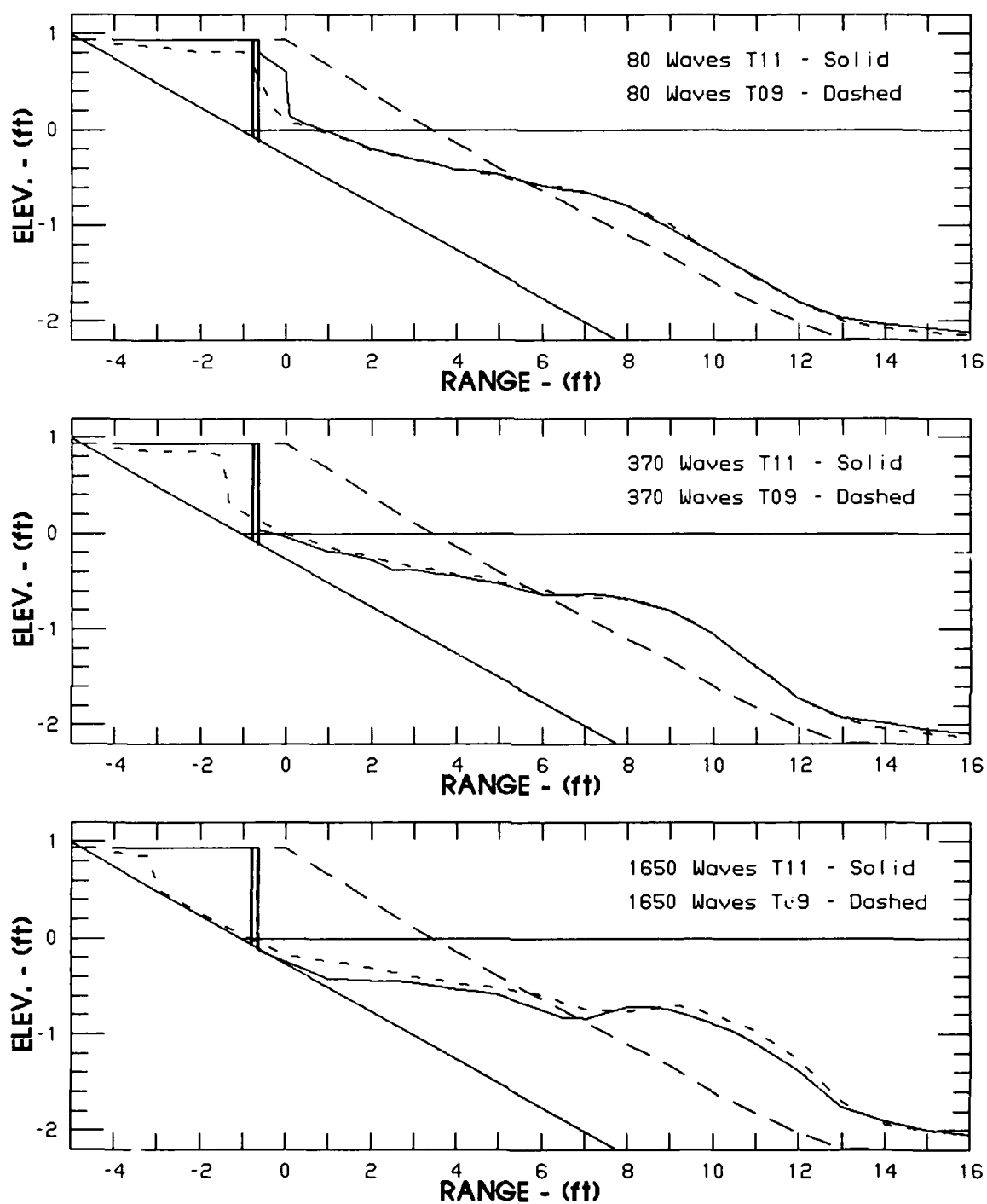


Figure 32. Seawall impact under irregular waves, T11 versus T09

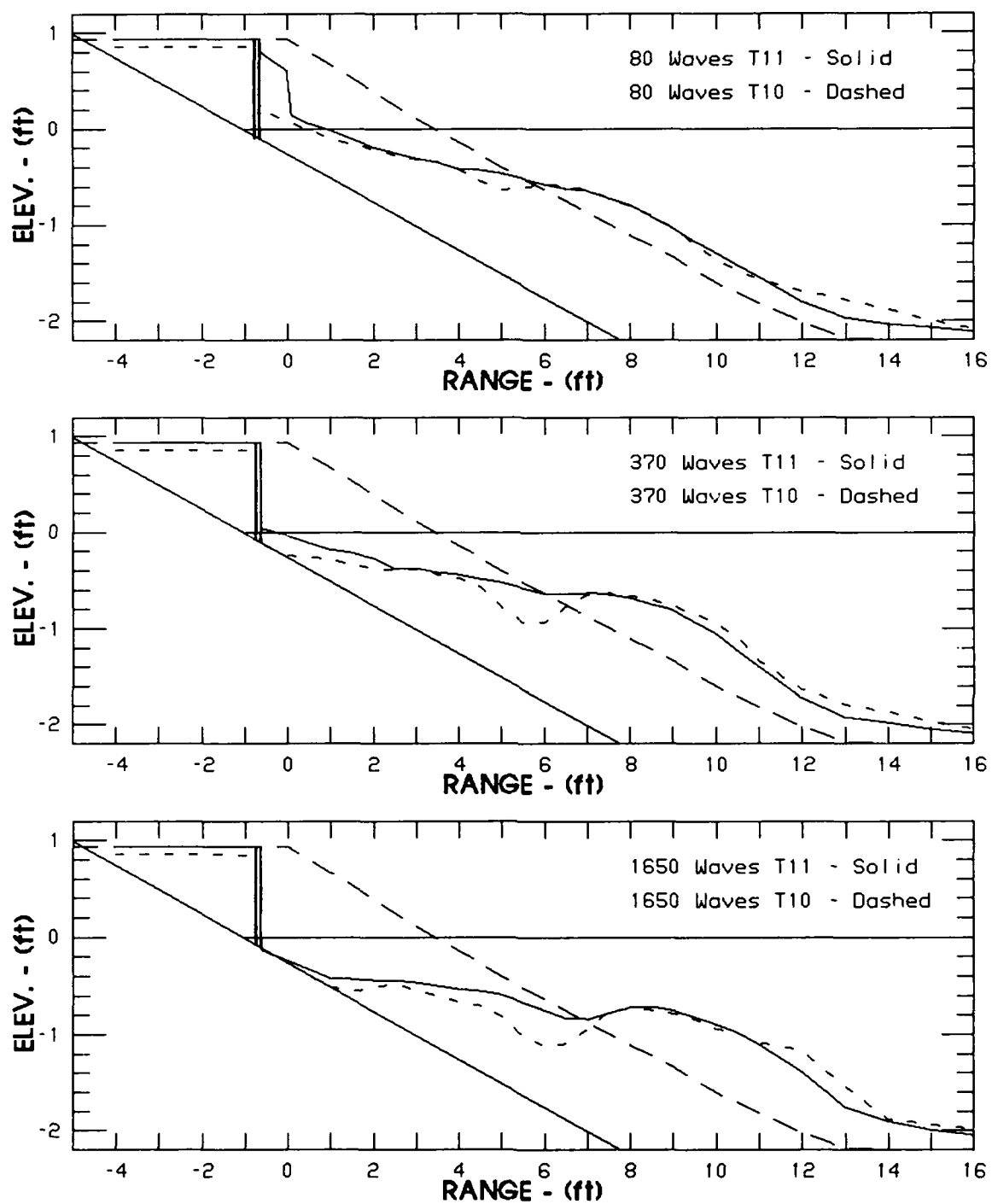


Figure 33. Seawall irregular wave comparison,  $H_{1/3}$  equals  $H_{mono}$

the no-time-lag comparisons in Figure 33. This was also previously noted in Part VI and demonstrated by Figure 29 for the comparisons with no vertical seawall.

## Vertical Seawall Summary and Conclusions

223. Modification of the basic testing arrangement in the 6-ft flume by addition of a vertical seawall provided the opportunity to examine Dean's *approximate principle*, which states that the volume of the additional scour in front of the seawall is approximately equal to the volume of sediment denied to the profile by the seawall. Comparison of regular wave tests (with and without the vertical seawall) supported the *approximate principle*, when averaged over the cross-tank profile variations, exhibiting a ratio of 1.03 for eroded volume over retained volume. Comparison tests using irregular waves were more uniform in the cross-tank dimension, but less erosion was observed, with a ratio of 0.83 for eroded over retained volume. Both results give ratios higher than that obtained by Barnett (1987); however, the present results represent only one condition, whereas Barnett's results stem from 11 different test cases.

224. Comparison between vertical seawall tests using both irregular waves and regular waves support the earlier conclusion that the irregular wave height parameter  $H_{1/3}$  provides best correspondence to the monochromatic wave height in terms of profile development. The regular wave period was represented by the peak spectral period.

225. Time for profile development under irregular wave action lagged the development caused by regular waves by a factor of approximately two. This also conforms to conclusions given earlier based on tests without a vertical seawall.

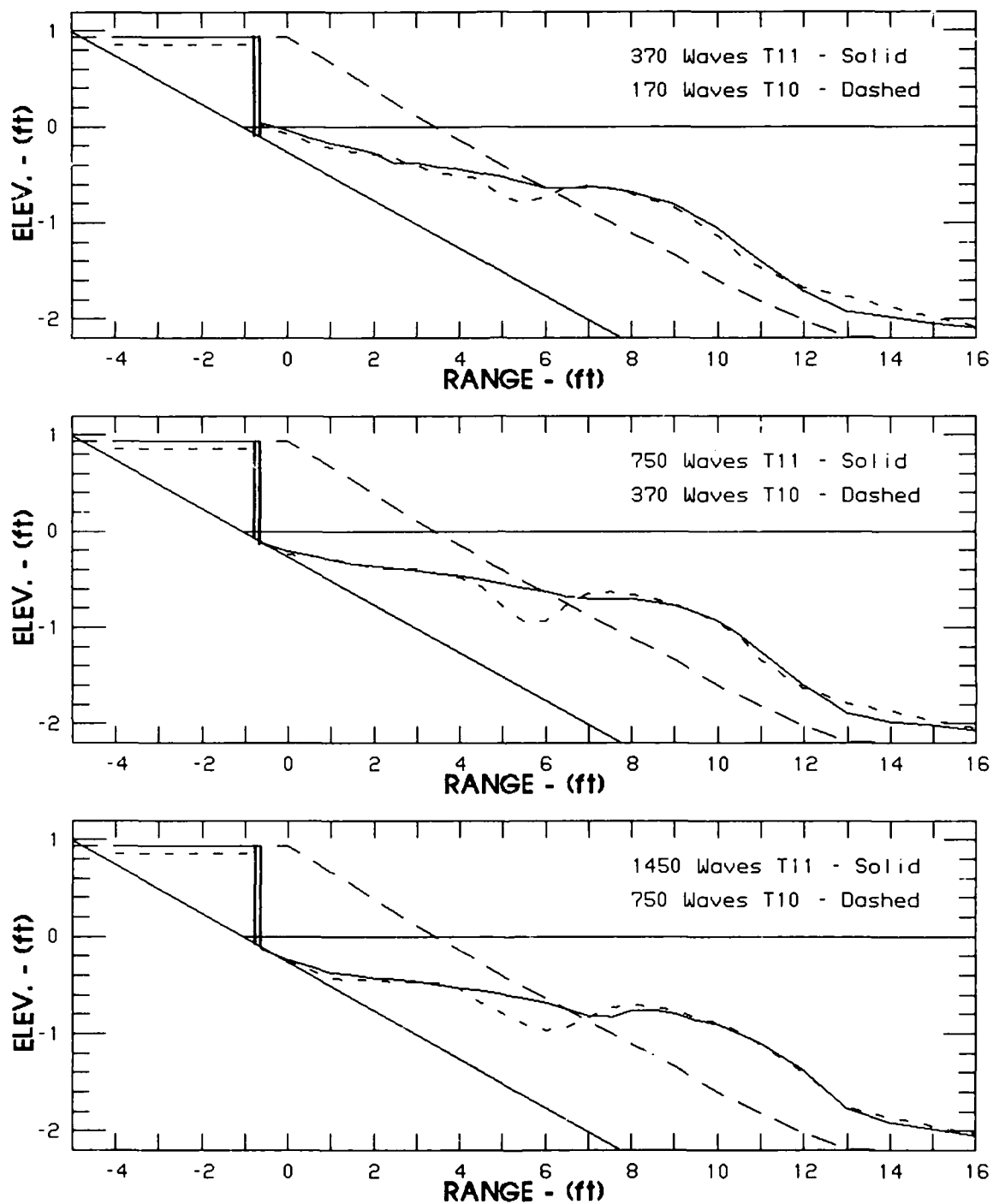


Figure 34. Time-shifted seawall comparison with irregular waves,  $H_{1/3}$  equals  $H_{mono}$

## PART VIII: SUMMARY OF RESULTS

226. Preceding sections of this report describe movable-bed physical model tests designed and conducted primarily to validate a selected set of scaling criteria for use in studying scour at and near coastal structures. A summary of the study results is presented below.

### Summary

227. A review of proposed movable-bed model scaling criteria applicable to turbulence-dominated regimes supported the criterion of maintaining the same value of the dimensionless sediment fall speed parameter between the model and the prototype situation. Two additional criteria for the selected guidance were that the model should be undistorted and hydrodynamics should be scaled according to the Froude scaling relationship. These criteria were adopted for testing and verification in this study. A similar sediment transport parameter suggested by Xie (1981) was examined and shown to be quite similar for turbulence-dominated situations. Applicability of the selected model scaling relationships was discussed, noting that most experience with this particular guidance was in 2-D situations.

228. Prototype-scale experiments conducted in the Großer Wellenkanal served as the prototype to be reproduced at scale in CERC's 6-ft wave flume. Tests using both regular and irregular wave trains were conducted at a prototype-to-model scale of 7.5:1, and the testing procedures were designed to duplicate those used in the GWK tests.

229. In the regular wave verification test where the sloping concrete revetment was exposed, a reasonable comparison between the model and the prototype profile evolution was obtained. However, the comparison improved when the model wave height was increased by about 10 percent over the original scaled value. An explanation for this discovery was given in terms of the difference in Xie's parameter between prototype and model in the offshore region. Increasing the wave height resulted in closer agreement of Xie's parameter between prototype and model, and sediment was moved farther offshore in the model. The resulting increased erosion of the inshore region adjacent to the exposed sloping revetment gave support to the concept that the offshore bar has a sediment storage capacity for a particular wave climate, and as long as this climate persists, the inshore region will continue to erode until this capacity is met.

230. Validation of the selected scaling criteria using irregular waves was considered highly successful. The model exhibited profile development that compared very well with the prototype profile development when the revetment was not exposed to wave action. In the irregular wave test, no increase in wave height was required as was done for the regular wave tests using the Xie parameter. Apparently, irregular wave

conditions extend the region of suspended sediment movement farther offshore due to variations in the location at which the waves break.

231. Experiment repeatability was shown to be well within acceptable limits, and overall, the attempts to validate the modeling guidance for the case of turbulence-induced scour of noncohesive sediment was judged by the authors to be successful. However, it was noted at present that this verification is encouraging only to the extent that prototype-scale wave tank tests can reproduce natural beach response without adverse laboratory effects.

232. Model tests in which wave parameters were slightly changed were conducted to assess the importance of the fall speed parameter on the profile response. Increasing the height of regular waves by 10 percent promoted additional offshore transport of sediment, as did decreasing the wave period by 10 percent. Similar profile development was seen when these slight variations in wave parameters resulted in the same value for the fall speed parameter, but this distortion of Froude-scaled hydrodynamics was not recommended for other than slight perturbations in the wave parameters.

233. Initial profile differences in the model experiments did not substantially affect the ultimate outcome of the experiments as the profile approached near-equilibrium; however, short-term differences were observed. It is possible that great differences in initial profile slopes could have an impact on final profile configuration, but no tests were conducted with radically different initial slopes.

234. Movable-bed tests in which the sloping revetment became exposed were conducted using irregular waves to determine which irregular wave parameter is best suited for use in comparing results from regular-wave tests. Best results at equilibrium were obtained when the significant wave height of the irregular waves was equivalent to the regular wave height, even though the irregular waves contained about 30 percent less total energy. Equivalent profile development took about twice as long under irregular waves, and a simple explanation is that the irregular wave train included accretive as well as erosive waves and it appeared that the larger waves were most responsible for profile development.

235. Placement of a vertical seawall on the sloping revetment effectively denied the profile of the sand shoreward of the seawall. Both regular and irregular wave tests were conducted to examine the 2-D impacts of this situation. The additional erosion observed in front of the seawall was approximately equal to the amount of sediment being held behind the seawall that otherwise would have eroded if the seawall were absent. For the irregular wave case, the additional eroded volume in front of the seawall was about 83 percent of the amount being withheld by the seawall. These findings are generally in agreement with results obtained by others. Comparisons between the irregular and regular wave tests with the seawall intact confirmed that making  $H_{1/3}$  of the irregular waves equal to  $H_{mono}$  gives best correspondence between profile erosion tests.

## Conclusions

236. Based on results obtained in this study, several important conclusions can be made about 2-D small-scale movable-bed physical modeling of coastal scour.

- a. Mid-scale test results support preservation of the dimensionless fall speed parameter in an undistorted Froude model as a viable method of scaling models intended to replicate wave erosion under turbulence-dominated situations. The guidance has been verified for 2-D cases, and must be further validated before it can be fully recommended for 3-D movable-bed model tests.
- b. For tests involving regular waves, model designers should consider augmenting the Froude-scaled experimental wave height to provide better prototype-to-model correspondence of the Xie parameter in the offshore region. This correspondence should be limited to the more active portions of the offshore and need not extend out to closure depth.
- c. Tests conducted using irregular waves do not require the augmentation described in (b) above.
- d. Small perturbations in the fall speed parameter between prototype and model can be tolerated without significant impact; however, this should be avoided if possible.
- e. Models in which temporal profile evolution results are important should begin with a reasonable approximation of the natural beach profile molded into the model. Accuracy in the offshore region is more important than surf zone detail.
- f. Comparable profile development can be achieved between regular and irregular wave models when the irregular significant wave height,  $H_{1/3}$ , is equal to the regular wave height. Profile development will take between two and three times as long in the irregular wave model.
- g. Dean's (1986) concept that the additional erosion experienced in front of a seawall is approximately equal to the amount of sediment behind the seawall that would erode in the seawall's absence seems to hold for the 2-D situation investigated in the wave flume.

237. Further examination of these experimental results by others may reveal additional insights overlooked by the authors or inconsistencies in the conclusions stated above. Such scrutiny is desirable and encouraged by the authors in the spirit of scientific discovery.

## REFERENCES

- Barnett, M. R. 1987. "Laboratory Study of the Effects of a Vertical Seawall on Beach Profile Response," Report 87/005, Coastal and Oceanographic Engineering Department, University of Florida, Gainesville, FL.
- Barnett, M. R., and Wang, H. 1988. "Effects of a Vertical Seawall on Profile Response," *Proceedings of the 21th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1493-1507.
- Bijker, E. W. 1967. "Some Considerations about Scales for Coastal Models with Movable Bed," Publication No. 50, Delft Hydraulics Laboratory, Delft, The Netherlands.
- Birkemeier, W. A. 1980. "The Effect of Structures and Lake Level on Bluff and Shore Erosion in Berrigen County, Michigan," Miscellaneous Report 80-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Dalrymple, R. A. 1985. "Introduction to Physical Models in Coastal Engineering," in *Physical Modelling in Coastal Engineering*, R. A. Dalrymple, Ed., A. A. Balkema, Rotterdam, The Netherlands, pp 3-9.
- Dalrymple, R. A., and Thompson, W. W. 1976. "Study of Equilibrium Beach Profiles," *Proceedings of the 15th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1277-1296.
- Dean, R. G. 1973. "Heuristic Models of Sand Transport in the Surf Zone," *Proceedings of the Conference on Engineering Dynamics in the Surf Zone*, Sydney, Australia, pp 208-214.
- \_\_\_\_\_. 1985. "Physical Modeling of Littoral Processes," in *Physical Modelling in Coastal Engineering*, R. A. Dalrymple, Ed., A. A. Balkema, Rotterdam, The Netherlands, pp 119-139.
- \_\_\_\_\_. 1986. "Coastal Armoring: Effects, Principles and Mitigation," *Proceedings of the 20th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 3, pp 1843-1857.
- Dette, H. H., and Uliczka, K. 1986. "Prototype and Model Evolution of Beach Profile," *Symposium on Scale Effects in Modelling Sediment Transport*, International Association of Hydraulic Research, pp 35-48.
- \_\_\_\_\_. 1987. "Prototype Investigation on Time-Dependent Dune Recession and Beach Erosion," *Proceedings of Coastal Sediments '87*, American Society of Civil Engineers, Vol 2, pp 1430-1444.
- Fan, L. N., and Le Méhauté, B. 1969. "Coastal Movable Bed Model Technology," Technical Report No. TC-131, Tetra Tech, Inc., Pasadena, CA.



- Fowler, J. E., and Smith, E. R. 1986. "Evaluation of Movable-Bed Modeling Guidance," *Proceedings of the Third International Symposium on River Sedimentation*, American Society of Civil Engineers, pp 1793-1802.
- \_\_\_\_\_. 1987. "Evaluation of Sand as a Modeling Material Using Vellinga's Guidance," *Proceedings of the 1987 National Conference on Hydraulic Engineering*, American Society of Civil Engineers, pp 684-689.
- Gourlay, M. R. 1980. "Beaches: Profiles, Processes and Permeability," *Proceedings of the 17th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1320-1339.
- Hallermeier, R. J. 1980. "Sand Motion Initiation by Water Waves: Two Asymptotes," *Journal of the Waterway, Port, Coastal and Ocean Division*, Vol 106, No. WW3, pp 299-318.
- \_\_\_\_\_. 1981. "Terminal Settling Velocity of Commonly Occurring Sand Grains," *Sedimentology*, Vol 28, pp 859-865.
- Howd, P. A., and Birkemeier, W. A. 1987. "Storm-Induced Morphology Changes During DUCK85," *Proceedings of Coastal Sediments '87*, American Society of Civil Engineers, Vol 1, pp 834- 847.
- Hudson, R. Y., Herrmann, F. A., Sager, R. A., Whalin, R. W., Keulegan, G. H., Chatham, C. E., and Hales, L. Z. 1979. "Coastal Hydraulic Models," Special Report No. 5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Hughes, S. A. 1983. "Movable-Bed Modeling Law for Coastal Dune Erosion," *Journal of Waterway, Port, Coastal, and Ocean Engineering Division*, Vol 109, No. 2, pp 164-179.
- \_\_\_\_\_. 1984. "Closure to Movable-Bed Modeling Law for Coastal Dune Erosion," by S. Hughes *Journal of Waterway, Port, Coastal, and Ocean Engineering Division*, Vol 110, No. 4, pp 504-507.
- Hughes, S. A., and Borgman, L. E. 1987. "Beta-Rayleigh Distribution for Shallow Water Wave Heights," *Proceedings of Coastal Hydrodynamics '87*, American Society of Civil Engineers, pp 17-31.
- Hughes, S. A., and Chiu, T. Y. 1981. "Beach and Dune Erosion During Severe Storms," UFL/COEL-TR/043, Coastal and Oceanographic Engineering Department, University of Florida, Gainesville, FL.
- Iwagaki, Y., and Noda, H. 1963. "Laboratory Studies of Scale Effects in Two-Dimensional Beach Processes," *Proceedings of the 8th Coastal Engineering Conference*, American Society of Civil Engineers, pp 194-210.
- Kamphuis, J. W. 1982. "Coastal Mobile Bed Modelling from a 1982 Perspective," C. E. Research Report No. 76, Queen's Univeristy, Kingston, Ontario.

- Kraus, N. C. 1988. "The Effects of Seawalls on the Beach: An Extended Literature Review," *Journal of Coastal Research*, Special Issue No. 4, N. C. Kraus and O. H. Pilkey, Eds., pp 1-28.
- Kriebel, D. L. 1987. "Beach Recovery Following Hurricane Elena," *Proceedings of Coastal Sediments '87*, American Society of Civil Engineers, Vol 1, pp 990-1005.
- Kriebel, D. L., Dally, W. R., and Dean, R. G. 1986a. "Undistorted Froude Model for Surf Zone Sediment Transport," *Proceedings of the 20th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1296-1310.
- \_\_\_\_\_. 1986b. "Beach Profile Response Following Severe Erosion Events," UFL/COEL-86/016, Coastal and Oceanographic Engineering Department, University of Florida, Gainesville, FL.
- Lappo, D. D., and Koshelnik, Y. I. 1988. "Modeling of Wave Erosion of Sandy Beaches," *Fluid Mechanics - Soviet Research*, Vol 17, No. 4, pp 120-130.
- Larson, M. 1988. "Quantification of Beach Profile Change," Report No. 1008, Department of Water Resources Engineering, Lund University, Lund, Sweden.
- Larson, M., and Kraus, N. C. 1989. "SBEACH: Numerical Model for Simulating Storm-Induced Beach Change; Report 1, Empirical Foundation and Model Development," Technical Report CERC-89-9, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Le Méhauté, B. 1970. "A Comparison of Fluvial and Coastal Similitude," *Proceedings of the 12th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1077-1096.
- Mimura, N., Otsuka, Y., and Watanabe, A. 1986. "Laboratory Study on Two-Dimensional Beach Transformation Due to Irregular Waves," *Proceedings of the 20th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1393- 1406.
- Nayak, I. V. 1970. "Equilibrium Profiles of Model Beaches," Technical Report HEL-2-25, Hydraulic Engineering Laboratory, University of California, Berkeley, CA.
- \_\_\_\_\_. 1971. "Equilibrium Profiles of Model Beaches," *Proceedings of the 12th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1321-1340.
- Noda, E. K. 1971. "Coastal Movable-Bed Scale-Model Relationship," Report TC-191, Tetra Tech, Inc., Pasadena, CA.
- Penchev, V., Sotkova, M., and Dragncheva, D. 1986. "Comparative Model Investigations of Artificial Beach Behind Underwater Sill in Different Scales," *Symposium on Scale Effects in Modelling Sediment Transport*, International Association of Hydraulic Research, pp 300- 310.

- Pilkey, O. H., and Wright, H. L. 1988. "Seawalls Versus Beaches," *Journal of Coastal Research*, Special Issue No. 4, N. C. Kraus and O. H. Pilkey, Eds., pp 41-64.
- Powell, K. A. 1987. "Toe Scour at Sea Walls Subject to Wave Action," Report SR 119, Hydraulic Research Limited, Wallingford, UK.
- Saville, T. 1957. "Scale Effects in Two Dimensional Beach Studies," *Transactions from the 7th General Meeting of the International Association of Hydraulic Research*, Vol 1, pp A3-1-A3-10.
- Sayao, O. J. 1984. "Discussion of Movable-Bed Modeling Law for Coastal Dune Erosion," by S. Hughes, *Journal of Waterway, Port, Coastal, and Ocean Engineering Division*, Vol 110, No. 4, pp 493-495.
- Sayao, O. J., and Guimaraes, J.C. 1984. "Experimental Verification of Similarity Criteria for Equilibrium Beach Profiles," *Proceedings of the 19th Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1342-1359.
- Sayao, O. J., and Nairn, R. B. 1988. "Physical Modeling of Beach Erosion and Littoral Drift," *Proceedings of the 21st Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 181-1832.
- Schulz, G. 1985. "Investigations about the Influence of Natural Beaches and Man-Made Foreshores on the Attack of Seadikes," (in German), M.S. Thesis, Technical University of Braunschweig, Braunschweig, Federal Republic of Germany.
- Thompson, E. F., and Vincent, C. L. 1984. "Shallow Water Wave Height Parameters," *Journal of Waterway, Port, Coastal, and Ocean Engineering Division*, Vol 110, No. 2, pp 293-299.
- \_\_\_\_\_. 1985. "Significant Wave Height for Shallow Water Design," *Journal of Waterway, Port, Coastal, and Ocean Engineering Division*, Vol 111, No. 5, pp 828-842.
- Turner, K. A., and Durham, D. L. 1984. "Documentation of Wave Height and Tidal Analysis Programs for Automated Data Acquisition and Control Systems," Miscellaneous Paper HL-84-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Uliczka, K., and Dette, H. H. 1987. "Prototype Investigation on Time-Dependent Dune Recession and Beach Erosion," *Proceedings of Coastal Sediments '87*, American Society of Civil Engineers, Vol 2, pp 1430-1444.
- \_\_\_\_\_. 1988. "About the Influence of Erosion Volume on Cross-Shore Sediment Movement at Prototype Scale," *Proceedings of the 21st Coastal Engineering Conference*, American Society of Civil Engineers, Vol 2, pp 1721-1735.

- Vellinga, P. 1982. "Beach and Dune Erosion During Storm Surges," *Coastal Engineering*, Vol 6, No. 4, pp 361-387.
- \_\_\_\_\_. 1984. "Discussion of Movable-Bed Modeling Law for Coastal Dune Erosion," by S. Hughes, *Journal of Waterway, Port, Coastal, and Ocean Engineering Division*, Vol 110, No. 4, pp 495-504.
- \_\_\_\_\_. 1986. "Beach and Dune Erosion During Storm Surges," Ph.D. Dissertation, Communication No. 372, Delft Hydraulics Laboratory, Delft, The Netherlands.
- Xie, S.-L. 1981. "Scouring Patterns in Front of Vertical Breakwaters and Their Influences on the Stability of the Foundations of the Breakwaters," Department of Civil Engineering, Delft University of Technology, Delft, The Netherlands.
- \_\_\_\_\_. 1985. "Scouring Patterns in Front of Vertical Breakwaters," *Acta Oceanologica Sinica*, Vol 4, No. 1, pp 153-164.
- Yalin, M. S. 1971. *Theory of Hydraulic Models*, MacMillan Press, London, England.

## APPENDIX A: DESCRIPTION OF WAVE ANALYSIS

### Data Acquisition and Analysis

1. Wave gages in the physical model were calibrated prior to collecting data. This was done by moving gage sensor rods through a series of vertical steps to obtain calibration coefficients from a least-squares linear or quadratic fit of the voltage versus submerged gage position. The US Army Engineer Waterways Experiment Station (WES) process IDCAL ensures that proper gage potentiometer coefficients are used, and it also generates descriptive information for documenting and archiving test output and data files. Wave data were collected in real-time, with a sampling rate of 20 Hz. Data acquisition and the wave board are driven by another WES process labeled SPLASH2. To assure smooth transition of the wave board between successive points, the command signal rate was set at 20 Hz.

2. Prior to data analysis, the calibration coefficients and header information created by the process IDCAL are combined with the water surface elevation data collected by process SPLASH2 and converted to engineering units for analysis by the WES process Time Series Analysis File (TSAF). Program TSAF is designed such that a user-defined process control file can be used to select which types of analysis to perform on the data. Among the analyses available in TSAF are single channel frequency analysis, multiple channel upcrossing analysis, multiple channel downcrossing analysis, and Goda analysis. The process control file contains information regarding how much of a particular data record to analyze, which channels are to be used in the data analysis, plotting instructions, whether or not to save certain values, and several other options. Hard copy output from TSAF can be in the form of printouts of parameters chosen, frequency plots, and strip charts as discussed below.

### Time Series Analysis File (TSAF)

3. The following description of the TSAF package is abstracted from Briggs<sup>1</sup> and the TSAF package itself. Readers desiring more complete descriptions of the processes mentioned here should consult these references. In the TSAF code, the program reads and performs both time and frequency domain analysis on the collected water surface elevation data. In these analyses, the code assumes that the water surface

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<sup>1</sup>Briggs, M. J. 1988. "Unidirectional Spectral Wave Generation and Analysis in Wave Basins," Volume I, Technical Report CERC-88-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS

elevation time series are discrete, real-valued sequences with equal time intervals of  $t = n\Delta t$  with  $\Delta t$  the data collection interval. The total length of a time series is given by  $T = N\Delta t$  where  $N$  is the total number of data points. The TSAF code consists of 11 processes that may or not be used during the data analysis sequence. These processes are concerned with either time domain or frequency domain analyses and are listed in Table A1.

Table A1. Analysis Options

Time Domain	Frequency Domain
Strip charts of raw data*	Single channel frequency response*
Zero upcrossing*	Frequency response between 2 channels
Zero downcrossing*	Cross spectral density
Crest height	Goda reflection analysis*
Trough height	
Coherence function	
Auto- and cross-correlation	

\*Denotes those used in present study.

4. The strip chart option simply plots the raw time series data for one or more of the available gages. The time series plots are scaled to facilitate/enhance readability and presentability. An example of a strip chart plot of a typical raw water elevation time record recorded during an irregular wave test is presented at Figure A1. Examples of the output from the TSAF analysis program are presented at Figures A2-A4. The tables in Appendix B are derived from such output.

5. For the up and downcrossing analyses, the program calculates statistics of wave elevation, wave height, and period for the datum selected. This datum is typically the mean, but can be externally imposed. For the surface elevation, the mean, root mean square, standard deviation, minimum, and maximum values are calculated. Wave heights and periods corresponding to the difference between the minimum and maximum values between consecutive up or downcrossings are calculated (Figure A2). Averages of these values for each three-gage array are also computed (Figure A4). Also, the total number of waves (zero up or downcrossings) and maximum wave height are provided. Wave heights for each gage are saved for later plotting and use with other processes. If desired, cumulative probabilities and Weibull distributions can be fitted and plotted.

6. Spectral densities are calculated for each of the individual gages after detrending and windowing the time series (Figure A3). Detrending options include removing the mean or a linear or second-order trend. Window options include 10- to 50-percent cosine bell or cubic polynomial. The data are Fourier transformed, band averaged between lower and upper cutoff frequencies, and plotted. Measured spectral estimates for each gage are then used in the calculation of frequency response estimates and reflection

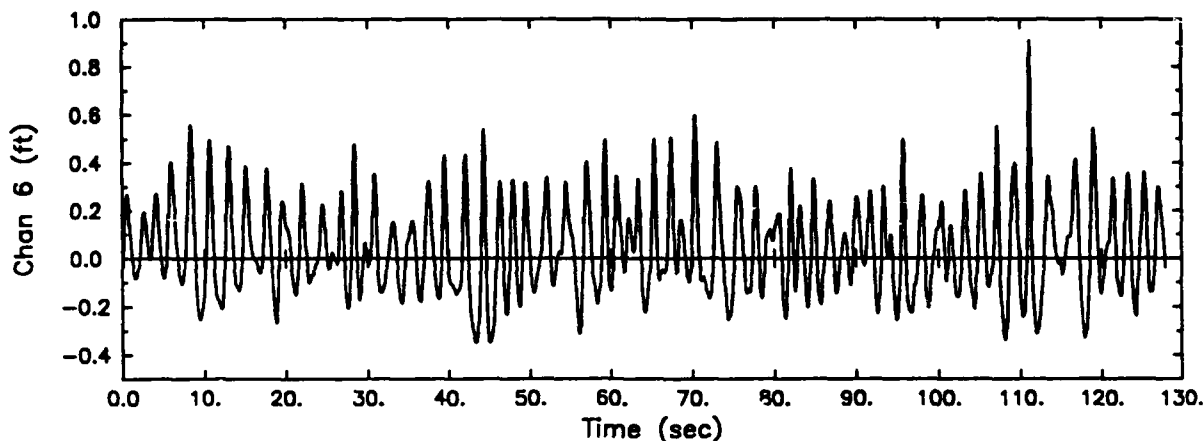


Figure A1. Irregular wave surface elevation time series

*****									
* DOWNCROSSING ANALYSIS (PAGE 1) *									
* 6 FT SCOUR TESTS, SPECTRAL, ST14W05A *						* ANALYSIS DATE 5-OCT-89 *			
* TIME STEP = 0.5000E-01 * NUMBER OF TIME STEPS CONSIDERED =						* ANALYSIS TIME 1356 *			
* 3200 *									
*****									
DATA CHANNEL = 1		CROSSING MODE = RECORD MEAN		DATUM VALUE = -0.9802E-02		PLOTTED RESULTS? NO		PLOT MODE = 0	
ETABAR = -0.9802E-02		ETAMIN = -0.6102		T 1/3 = 2.092		H 1/3 = 0.6750		WEIBULL ALPHA = 1.762	
ETARMS = 0.1817		ETAMAX = 0.5708		TBAR = 1.869		HBAR = 0.4531		WEIBULL BETA = 0.5812	
ETASD = 0.1818		RHOHH = 0.4561		RHOHT = 0.5770		HMAX = 1.168		NUMBER OF WAVES = 84	
*****									
DATA CHANNEL = 2		CROSSING MODE = RECORD MEAN		DATUM VALUE = -0.1347E-01		PLOTTED RESULTS? NO		PLOT MODE = 0	
ETABAR = -0.1347E-01		ETAMIN = -0.6015		T 1/3 = 2.101		H 1/3 = 0.6888		WEIBULL ALPHA = 2.213	
ETARMS = 0.1848		ETAMAX = 0.6915		TBAR = 1.909		HBAR = 0.4678		WEIBULL BETA = 0.4916	
ETASD = 0.1848		RHOHH = 0.4665		RHOHT = 0.4796		HMAX = 1.293		NUMBER OF WAVES = 83	
*****									
DATA CHANNEL = 3		CROSSING MODE = RECORD MEAN		DATUM VALUE = -0.1312E-01		PLOTTED RESULTS? NO		PLOT MODE = 0	
ETABAR = -0.1312E-01		ETAMIN = -0.5239		T 1/3 = 2.105		H 1/3 = 0.6986		WEIBULL ALPHA = 2.112	
ETARMS = 0.1836		ETAMAX = 0.6761		TBAR = 1.909		HBAR = 0.4655		WEIBULL BETA = 0.5092	
ETASD = 0.1836		RHOHH = 0.3986		RHOHT = 0.4652		HMAX = 1.200		NUMBER OF WAVES = 83	
*****									
DATA CHANNEL = 4		CROSSING MODE = RECORD MEAN		DATUM VALUE = -0.1542E-01		PLOTTED RESULTS? NO		PLOT MODE = 0	
ETABAR = -0.1542E-01		ETAMIN = -0.3566		T 1/3 = 2.048		H 1/3 = 0.6456		WEIBULL ALPHA = 2.181	
ETARMS = 0.1642		ETAMAX = 0.6994		TBAR = 1.931		HBAR = 0.4191		WEIBULL BETA = 0.4931	
ETASD = 0.1642		RHOHH = 0.4944		RHOHT = 0.3515		HMAX = 0.9490		NUMBER OF WAVES = 81	
*****									
DATA CHANNEL = 5		CROSSING MODE = RECORD MEAN		DATUM VALUE = -0.1591E-01		PLOTTED RESULTS? NO		PLOT MODE = 0	
ETABAR = -0.1591E-01		ETAMIN = -0.3691		T 1/3 = 2.048		H 1/3 = 0.6361		WEIBULL ALPHA = 2.122	
ETARMS = 0.1645		ETAMAX = 0.6439		TBAR = 1.907		HBAR = 0.4147		WEIBULL BETA = 0.4923	
ETASD = 0.1645		RHOHH = 0.4536		RHOHT = 0.3731		HMAX = 0.9250		NUMBER OF WAVES = 82	
*****									
DATA CHANNEL = 6		CROSSING MODE = RECORD MEAN		DATUM VALUE = -0.1590E-01		PLOTTED RESULTS? NO		PLOT MODE = 0	
ETABAR = -0.1590E-01		ETAMIN = -0.4021		T 1/3 = 2.150		H 1/3 = 0.6674		WEIBULL ALPHA = 1.715	
ETARMS = 0.1695		ETAMAX = 0.6499		TBAR = 1.955		HBAR = 0.4221		WEIBULL BETA = 0.5704	
ETASD = 0.1695		RHOHH = 0.3991		RHOHT = 0.3108		HMAX = 0.9410		NUMBER OF WAVES = 80	
*****									

Figure A2. Example of single channel downcrossing analysis





```

*****
*                                CERC UNIDIRECTIONAL SPECTRAL INCIDENCE/REFLECTION ANALYSIS                                *
*                                6 FT SCOUR TESTS, SPECTRAL, ST14W05A                                *
*                                ANALYSIS DATE 5-OCT-89                                *
*                                ANALYSIS TIME 1356                                *
* OFFSHORE PROBE = DATA CHANNEL 4    CENTER PROBE = DATA CHANNEL 5    NEARSHORE PROBE = DATA CHANNEL 6    *
* DX12 = 1.000    WATER DEPTH = 2.200    DETREND MODE = 1 (MEAN REMOVED)    PLOTTED RESULTS? YES *
* DX13 = 3.000    GRAVITY = 32.20    WINDOW MODE = 1 (COSINE SQUARED)    10% OF RECORD TAPERED AT EACH END *
*                                TIME STEP = 0.5000E-01    NUMBER OF TIME STEPS ANALYZED = 3200    *
*****

MEAN UPCROSSING ANALYSIS RESULTS (AVERAGES OF RESULTS FROM THREE PROBES):
      ETABAR = -0.1574E-01    ETAMAX = 0.6644    H 1/3 = 0.6492    WEIBULL ALPHA = 1.989
      ETARMS = 0.1660    ETAMIN = -0.3759    T 1/3 = 2.128    WEIBULL BETA = 0.5219
      ETASD = 0.1661    HBAR = 0.4181    RHOHH = 0.5083
      HMAX = 0.9430    TBAR = 1.938    RHOHT = 0.3374

MEAN DOWNCROSSING ANALYSIS RESULTS (AVERAGES OF RESULTS FROM THREE PROBES):
      ETABAR = -0.1574E-01    ETAMAX = 0.6644    H 1/3 = 0.6497    WEIBULL ALPHA = 2.006
      ETARMS = 0.1660    ETAMIN = -0.3759    T 1/3 = 2.082    WEIBULL BETA = 0.5186
      ETASD = 0.1661    HBAR = 0.4186    RHOHH = 0.4490
      HMAX = 0.9383    TBAR = 1.931    RHOHT = 0.3451

DETRENDING RESULTS:  PROBE      A      B      C      FREQUENCY RANGE OVER WHICH SPECTRAL PARAMETERS
(VVALUES DEPEND ON OFFSHORE -0.1542E-01 0.0000E+00 0.0000E+00 ARE DETERMINED:
DETREND MODE IM- CENTER -0.1591E-01 0.0000E+00 0.0000E+00
POSED) NEARSHORE -0.1590E-01 0.0000E+00 0.0000E+00    LOW FREQUENCY LIMIT = 0.2000
HIGH FREQUENCY LIMIT = 5.000

PARAMETERS OF INCIDENT SPECTRUM:
      FPC = 0.4375    EM0 = 0.2773E-01    FPS = 0.4500
      TPC = 2.286    EM1 = 0.1444E-01    TPS = 2.222
      HMO = 0.6661    EM2 = 0.8291E-02    FPD = 0.4344
      QPG = 3.422    T02 = 1.329    TPD = 2.302

PARAMETERS OF REFLECTED SPECTRUM:
      FPC = 0.4375    EM0 = 0.2014E-02    FPS = 0.4125
      TPC = 2.286    EM1 = 0.1202E-02    TPS = 2.424
      HMO = 0.1795    EM2 = 0.9067E-03    FPD = 0.4125
      QPG = 2.908    T02 = 1.490    TPD = 2.424

MEAN REFLECTION COEFFICIENT = 0.2695
*****

```

Figure A4. Example of three-gage average values and reflection analysis (nearshore array)

monochromatic test. The upper record was obtained at the offshore array, while the lower record was measured at the nearshore array. The nonuniformity in the regular wave field did not impact the outcome of the experiments because it can be assumed that similar effects occurred in the large-scale experiments.

9. This nonuniformity in regular waves can, however, impact the results from the wave analysis program. Usually, a portion of the record containing between 30 to 50 waves was selected for analysis. Depending upon which section of record was analyzed, it was possible to obtain values for the statistical wave height parameters that showed considerable variation. For the most part, the same region of record was analyzed, but this was not always the case, and variations between nearshore averages seen in the Appendix B results can usually be attributed to this cause.

10. Variations in nearshore wave statistics between experiments that are claimed to have identical wave input may give the impression that the experiments were not the same, but the important point to remember is that these cases all had the same input wave board signal. Examination of the offshore wave statistics between experiments gives a better indication of the similarity of regular wave input.

11. The authors advise anyone who may use these experimental profile evolution results to validate numerical models that it would be better to drive the numerical model with the measured offshore wave

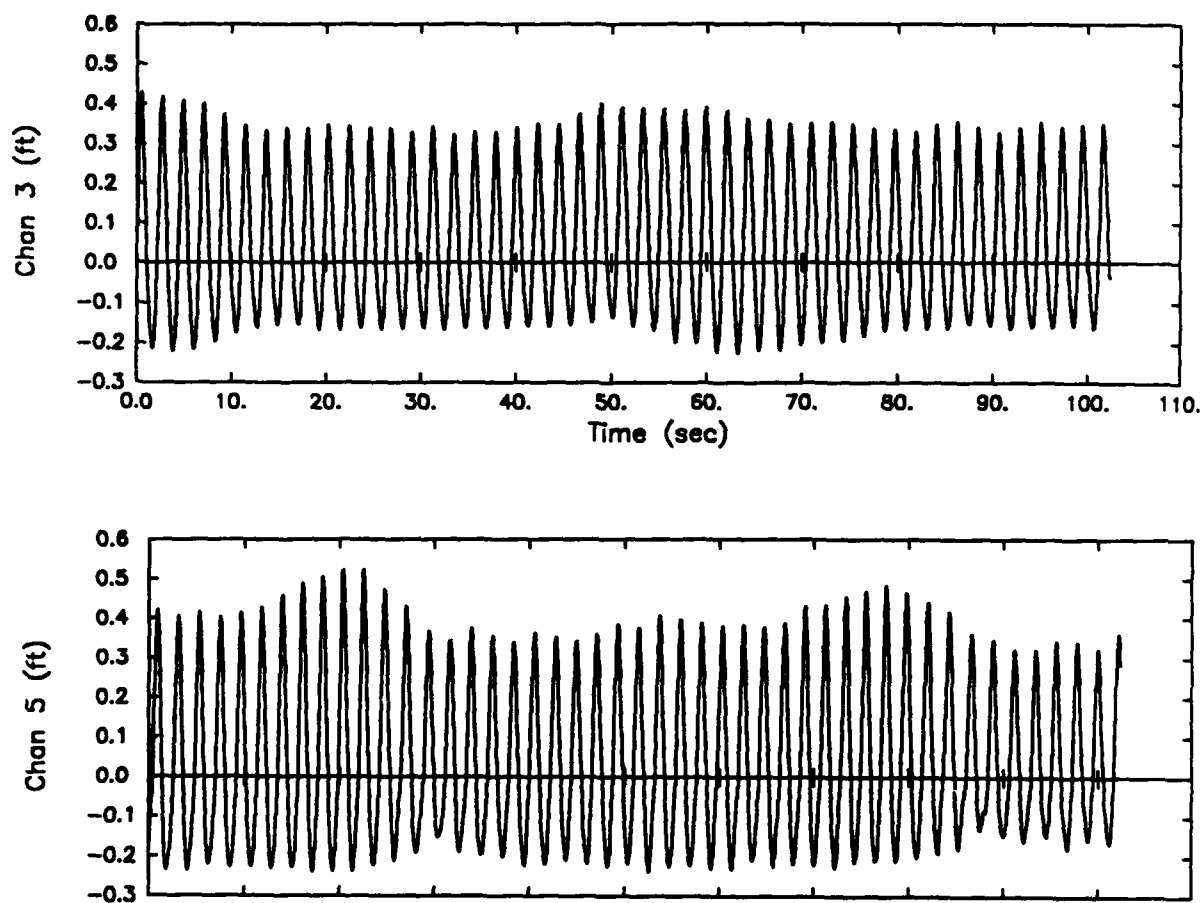


Figure A5. Typical regular wave measurement at offshore array (upper plot) and nearshore array (lower plot)

values rather than those values reported for the nearshore wave gage array.

12. Irregular wave analyses seemed to provide more stable statistical values between analyzed bursts. Figure A6 shows a typical wave record at the offshore array (upper plot) and the nearshore array (lower plot). However, reflection and nonlinear waves also influence the statistical results; and that combined with the relatively small number of waves analyzed probably explains the variations observed in the Appendix B tables for irregular wave experiments.

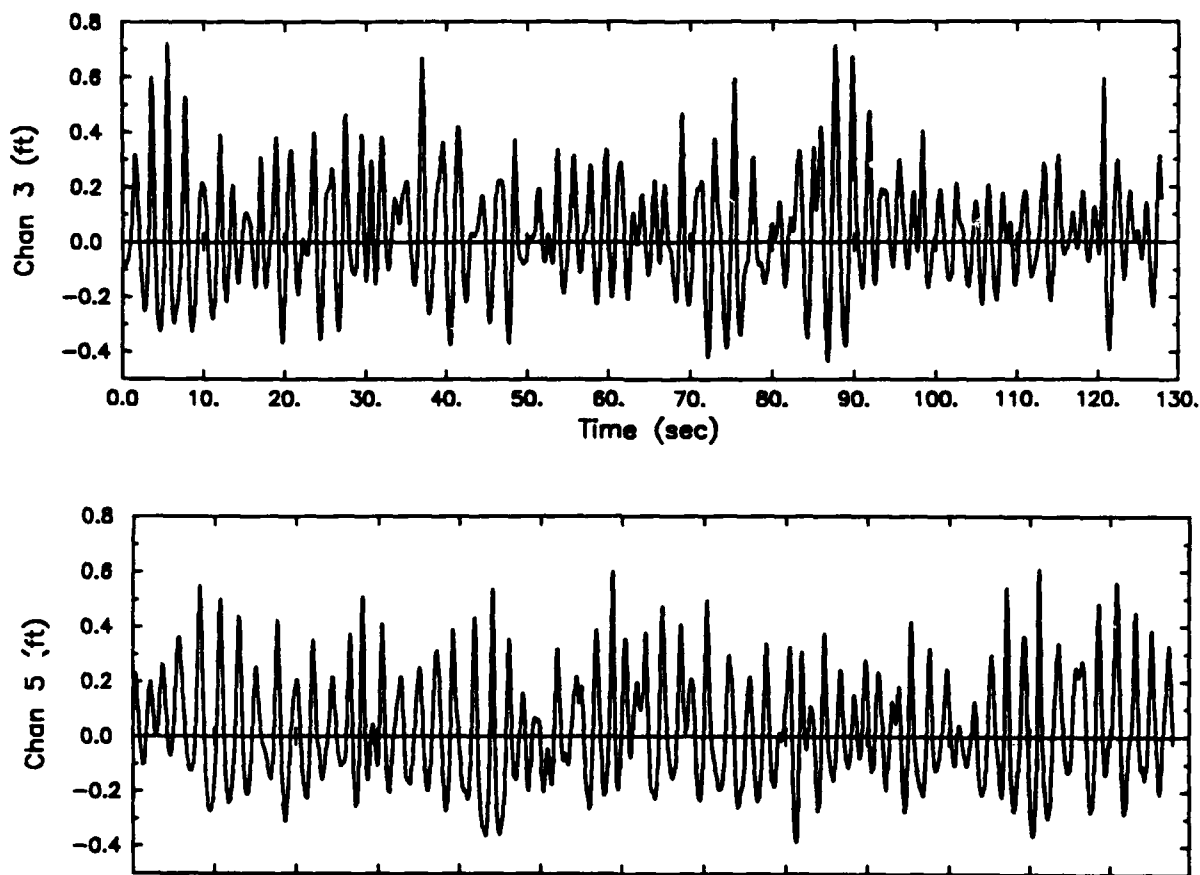


Figure A6. Typical irregular wave measurement at offshore array (upper plot) and nearshore array (lower plot)

## APPENDIX B: WAVE ANALYSIS RESULTS FOR EXPERIMENTS

1. This appendix contains analyzed results for the time series of water surfaces elevations collected by the gage arrays at the two locations in the wave flume during the experimental test series. Each documented experiment has a table of values for the offshore gage array and the nearshore gage array. All wave parameter values in each table represent the average of the three gages comprising the array.

2. Each wave data collection is denoted by a unique filename. The first two characters are the same for all files; the third and fourth characters represent the experiment number (e.g., T03); the fifth character is the same for all; the seventh and eighth characters correspond to a series of wave bursts between profiling stops; and the final character is the burst sequence within the wave series. For example, ST01W05A was the first set of waves run after a profiling stop, and ST01W05E was the final set, so five bursts of waves were run between profiling stops.

3. For all tables except Table B14, the column "Total Waves" is the approximate cumulative total of waves run in the wave flume. The corresponding column on Table B14 is labeled "Number Waves," and it gives the total analyzed number of irregular waves for each burst of waves.

4. The parameters listed on the tables are defined as below:

$H_{mo}$  - Energy-based significant wave height found as four times the standard deviation of sea surface elevations.

$H_{bar}$  - Average wave height as determined from zero down-crossing method.

$H_{1/3}$  - Significant wave height obtained as the average of the highest 1/3 waves determined from zero down-crossing method.

$H_{max}$  - Highest wave determined from zero down-crossing method.

$TpC$  - Wave period associated with the spectral peak.

$T_{bar}$  - Average wave period determined from zero down-crossing method.

$T_{1/3}$  - Average wave period associated with the highest 1/3 waves determined from zero down-crossing method.

Reflection coefficients were determined from analysis of the three gage array.

<u>Test</u>	<u>Description of Test</u>	<u>Table Number</u>
T01	Reproduction of prototype experiment using 10-m horizontal width berm	Table B1
T02	Repeat of T01 to demonstrate repeatability	Table B2
T03	Reproduction of prototype experiment using 11-m horizontal width berm (same as prototype)	Table B3
T04	Repeat of T03 with wave height increased by 10 percent to examine impact of height variations	Table B4
T05	Repeat of T03 using absorbing wave paddle	Table B5
T06	Repeat of T03 starting with the prototype profile at 40 waves molded in the flume	Table B6
T07	Repeat of T03 with wave period decreased 10 percent to examine impact of period variations	Table B7
T08	Repeat of T03 using irregular waves having $H_{1/3}$ equal to 110 percent of monochromatic wave height	Table B8
T09	Repeat of T03 using irregular waves having $H_{1/3}$ equal to the monochromatic wave height	Table B9
T10	Repeat of T03 using regular waves with a vertical seawall at the intersection of the revetment and still-water level	Table B10
T11	Repeat of T10 using irregular waves with $H_{1/3}$ equal to the monochromatic wave height	Table B11
T12	Undocumented repeat test of T08	Table B12
T13	Aborted irregular wave test	Table B13
T14	Reproduction of prototype irregular wave test	Table B14

Table B1. Test T01

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST01W01	40	0.804	0.541	0.634	0.643	2.172	2.199	2.201	0.046
ST01W02	80	0.889	0.631	0.637	0.643	2.172	2.200	2.202	0.045
ST01W03A	125	0.948	0.711	0.802	0.831	2.226	2.203	2.214	0.140
ST01W03B	170	0.974	0.753	0.849	0.896	2.226	2.195	2.210	0.201
ST01W04A	245	0.930	0.709	0.759	0.839	2.276	2.202	2.202	0.130
ST01W04B	320	0.885	0.627	0.651	0.676	2.179	2.201	2.203	0.079
ST01W04C	370			No Data Recorded					
ST01W05A	445	0.887	0.619	0.657	0.695	2.327	2.199	2.200	0.114
ST01W05B	520	0.893	0.629	0.691	0.742	2.113	2.199	2.199	0.126
ST01W05C	595	0.856	0.583	0.638	0.683	2.174	2.200	2.198	0.147
ST01W05D	670	0.884	0.612	0.663	0.695	2.179	2.200	2.202	0.149
ST01W05E	750	0.913	0.650	0.714	0.748	2.133	2.201	2.198	0.145
ST01W06A	825	0.891	0.619	0.710	0.759	2.133	2.198	2.200	0.145
ST01W06B	900	0.876	0.616	0.716	0.757	2.133	2.199	2.211	0.150
ST01W06C	975	0.861	0.579	0.638	0.696	2.133	2.199	2.201	0.175
ST01W06D	1050	0.862	0.586	0.640	0.679	2.179	2.199	2.190	0.172
ST01W06E	1125	0.866	0.586	0.643	0.680	2.133	2.198	2.199	0.169
ST01W06F	1200	0.854	0.575	0.634	0.674	2.179	2.198	2.202	0.184
ST01W06G	1275	0.871	0.592	0.641	0.691	2.133	2.198	2.199	0.177
ST01W06H	1350	0.890	0.621	0.707	0.741	2.327	2.198	2.198	0.160
ST01W06I	1425	0.892	0.632	0.735	0.770	2.179	2.199	2.205	0.153
ST01W06J	1450			No Data Recorded					
ST01W07A	1525	0.821	0.550	0.596	0.626	2.276	2.199	2.203	0.159
ST01W07B	1600	0.845	0.581	0.645	0.694	2.276	2.199	2.203	0.146
ST01W07C	1650	0.874	0.608	0.668	0.704	2.276	2.199	2.202	0.141
ST01W08	1850	0.837	0.571	0.613	0.643	2.156	2.199	2.204	0.136
ST01W09	2050	0.858	0.585	0.622	0.649	2.156	2.200	2.203	0.131
Averages		0.878	0.615	0.676	0.714	2.194	2.199	2.202	0.141

(Continued)

Table B1 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST01W01	40	0.391	0.297	0.540	0.618	2.312	2.005	2.201	0.367
ST01W02	80	0.617	0.548	0.699	0.725	2.172	2.366	2.195	0.472
ST01W03A	125	0.830	0.696	0.762	0.813	2.226	2.191	2.188	0.517
ST01W03B	170	0.861	0.713	0.792	0.869	2.179	2.186	2.199	0.509
ST01W04A	245	0.810	0.641	0.672	0.698	2.133	2.199	2.205	0.430
ST01W04B	320	0.813	0.635	0.664	0.694	2.276	2.198	2.174	0.442
ST01W04C	370			No Data Recorded					
ST01W05A	445	0.838	0.657	0.709	0.761	2.179	2.200	2.165	0.462
ST01W05B	520	0.860	0.661	0.738	0.801	2.133	2.204	2.163	0.490
ST01W05C	595	0.858	0.660	0.709	0.752	2.179	2.193	2.167	0.494
ST01W05D	670	0.862	0.667	0.747	0.794	2.276	2.198	2.155	0.504
ST01W05E	750	0.869	0.673	0.771	0.850	2.179	2.203	2.128	0.497
ST01W06A	825	0.833	0.647	0.740	0.810	2.226	2.210	2.173	0.453
ST01W06B	900	0.871	0.666	0.773	0.870	2.133	2.197	2.138	0.511
ST01W06C	975	0.828	0.637	0.713	0.786	2.133	2.208	2.175	0.492
ST01W06D	1050	0.836	0.654	0.689	0.731	2.179	2.192	2.177	0.472
ST01W06E	1125	0.834	0.645	0.717	0.765	2.133	2.208	2.175	0.464
ST01W06F	1200	0.834	0.649	0.705	0.767	2.179	2.200	2.167	0.472
ST01W06G	1275	0.837	0.648	0.696	0.737	2.276	2.202	2.188	0.466
ST01W06H	1350	0.839	0.660	0.736	0.782	2.226	2.207	2.170	0.450
ST01W06I	1425	0.868	0.665	0.767	0.827	2.133	2.202	2.155	0.486
ST01W06J	1450			No Data Recorded					
ST01W07A	1525	0.769	0.607	0.667	0.708	2.156	2.189	2.168	0.451
ST01W07B	1600	0.808	0.628	0.696	0.733	2.156	2.191	2.166	0.479
ST01W07C	1650	0.807	0.640	0.695	0.735	2.276	2.195	2.171	0.451
ST01W08	1850	0.770	0.606	0.662	0.710	2.185	2.200	2.173	0.435
ST01W09	2050	0.800	0.628	0.675	0.714	2.185	2.200	2.185	0.447
Averages		0.806	0.633	0.710	0.762	2.193	2.198	2.173	0.469

Table B2. Test T02

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST02W01A	40	0.875	0.623	0.631	0.648	2.172	2.200	2.202	0.055
ST02W02	80	0.870	0.608	0.632	0.635	2.108	2.198	2.202	0.044
ST02W03	170	0.948	0.720	0.836	0.895	2.133	2.203	2.210	0.219
ST02W04A	245	0.932	0.685	0.783	0.827	2.276	2.201	2.212	0.125
ST02W04B	320	0.891	0.639	0.682	0.747	2.276	2.202	2.205	0.080
ST02W04C	370			No Data Recorded					
ST02W05A	445	0.880	0.611	0.661	0.708	2.179	2.200	2.206	0.121
ST02W05B	520			No Data Recorded					
ST02W05C	595	0.921	0.650	0.727	0.769	2.179	2.201	2.195	0.149
ST02W05D	670	0.943	0.681	0.759	0.793	2.179	2.200	2.196	0.148
ST02W05E	750	0.914	0.631	0.743	0.800	2.133	2.201	2.203	0.162
ST02W06A	825	0.891	0.625	0.733	0.773	2.179	2.198	2.205	0.169
ST02W06B	900	0.848	0.564	0.662	0.718	2.276	2.198	2.198	0.189
ST02W06C	975	0.856	0.577	0.660	0.697	2.179	2.197	2.199	0.193
ST02W06D	1050	0.805	0.525	0.567	0.623	2.179	2.198	2.201	0.203
ST02W06E	1125	0.807	0.519	0.576	0.646	2.179	2.199	2.192	0.205
ST02W06F	1200	0.805	0.521	0.573	0.640	2.179	2.199	2.193	0.210
ST02W06G	1275	0.828	0.548	0.632	0.690	2.179	2.197	2.203	0.201
ST02W06H	1350	0.859	0.585	0.662	0.696	2.179	2.200	2.207	0.200
ST02W06I	1425	0.875	0.611	0.707	0.749	2.179	2.198	2.207	0.195
ST02W06J	1450			No Data Recorded					
ST02W07A	1525	0.832	0.546	0.631	0.701	2.179	2.201	2.189	0.204
ST02W07B	1600	0.852	0.584	0.684	0.734	2.276	2.197	2.194	0.180
ST02W07C	1650	0.538	0.332	0.544	0.637	2.133	2.215	2.195	0.289
Averages		0.856	0.590	0.671	0.720	2.187	2.200	2.201	0.169

(Continued)



Table B2 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST02W01A	40	0.565	0.396	0.604	0.660	2.172	2.419	2.196	0.453
ST02W02	80	0.557	0.565	0.709	0.744	2.108	2.181	2.168	0.476
ST02W03	170	0.873	0.710	0.808	0.875	2.179	2.190	2.207	0.557
ST02W04A	245	0.814	0.654	0.703	0.740	2.179	2.196	2.213	0.426
ST02W04B	320	0.811	0.644	0.680	0.719	2.276	2.203	2.185	0.438
ST02W04C	370			No Data Recorded					
ST02W05A	445	0.845	0.660	0.723	0.760	2.179	2.196	2.147	0.479
ST02W05B	520			No Data Recorded					
ST02W05C	595	0.858	0.674	0.770	0.834	2.133	2.197	2.149	0.482
ST02W05D	670	0.876	0.683	0.793	0.887	2.179	2.203	2.135	0.500
ST02W05E	750	0.843	0.650	0.762	0.860	2.179	2.207	2.168	0.476
ST02W06A	825	0.852	0.656	0.762	0.824	2.226	2.203	2.153	0.499
ST02W06B	900	0.833	0.650	0.720	0.771	2.179	2.197	2.175	0.493
ST02W06C	975	0.813	0.635	0.703	0.752	2.179	2.207	2.175	0.459
ST02W06D	1050	0.759	0.595	0.658	0.705	2.133	2.203	2.179	0.450
ST02W06E	1125	0.773	0.598	0.661	0.712	2.276	2.205	2.182	0.465
ST02W06F	1200	0.778	0.610	0.660	0.700	2.226	2.203	2.193	0.456
ST02W06G	1275	0.797	0.626	0.705	0.749	2.133	2.201	2.168	0.477
ST02W06H	1350	0.810	0.636	0.725	0.757	2.226	2.204	2.161	0.477
ST02W06I	1425	0.844	0.649	0.768	0.859	2.133	2.203	2.145	0.518
ST02W06J	1450			No Data Recorded					
ST02W07A	1525	0.812	0.623	0.712	0.768	2.276	2.199	2.172	0.489
ST02W07B	1600	0.815	0.637	0.728	0.782	2.179	2.209	2.166	0.480
ST02W07C	1650	0.731	0.504	0.683	0.800	2.179	2.080	2.176	0.514
<b>Averages</b>		0.793	0.622	0.716	0.774	2.187	2.205	2.172	0.479

Table B3. Test T03

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST03W01	40	0.883	0.624	0.627	0.628	2.389	2.202	2.203	0.063
ST03W02	80	0.892	0.632	0.634	0.637	2.389	2.200	2.201	0.064
ST03W03	170	1.037	0.817	0.858	0.887	2.226	2.202	2.213	0.186
ST03W04A	245	0.929	0.678	0.756	0.804	2.226	2.200	2.207	0.101
ST03W04B	320	0.893	0.636	0.682	0.725	2.327	2.199	2.196	0.078
ST03W04C	370	0.434	0.232	0.457	0.616	2.048	2.379	2.112	0.201
ST03W05A	445	0.866	0.594	0.634	0.657	2.226	2.203	2.201	0.128
ST03W05B	520	0.849	0.573	0.620	0.645	2.226	2.204	2.198	0.154
ST03W05C	595	0.853	0.572	0.631	0.669	2.327	2.203	2.192	0.164
ST03W05D	670	0.884	0.585	0.705	0.751	2.226	2.201	2.197	0.181
ST03W05E	750	0.840	0.555	0.611	0.640	2.226	2.201	2.197	0.205
ST03W06A	825	0.907	0.607	0.737	0.771	2.327	2.203	2.202	0.198
ST03W06B	900	0.905	0.610	0.765	0.807	2.327	2.203	2.206	0.194
ST03W06C	975	0.843	0.543	0.588	0.613	2.327	2.200	2.202	0.240
ST03W06D	1050	0.857	0.562	0.618	0.649	2.327	2.201	2.201	0.233
ST03W06E	1125	0.884	0.595	0.763	0.811	2.327	2.195	2.199	0.228
ST03W06F	1200	0.866	0.584	0.727	0.774	2.226	2.200	2.207	0.235
ST03W06G	1275	0.870	0.569	0.694	0.734	2.327	2.201	2.205	0.235
ST03W06H	1350	0.861	0.567	0.694	0.713	2.226	2.200	2.203	0.242
ST03W06I	1425	0.859	0.559	0.708	0.740	2.327	2.200	2.205	0.243
ST03W06J	1450			No Data Recorded					
ST03W07A	1525	0.854	0.567	0.697	0.737	2.226	2.199	2.202	0.251
ST03W07B	1600	0.855	0.572	0.656	0.674	2.327	2.201	2.210	0.249
ST03W07C	1650			No Data Recorded					
ST03W08	1850	0.896	0.604	0.712	0.742	2.327	2.204	2.201	0.230
Averages		0.862	0.584	0.677	0.714	2.281	2.209	2.198	0.187

(Continued)

Table B3 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST03W01	40	0.682	0.496	0.616	0.637	2.240	2.198	2.203	0.414
ST03W02	80	0.779	0.597	0.755	0.811	2.240	2.196	2.157	0.512
ST03W03	170	0.977	0.800	0.857	0.880	2.327	2.196	2.222	0.498
ST03W04A	245	0.901	0.712	0.763	0.787	2.226	2.191	2.212	0.448
ST03W04B	320	0.880	0.698	0.745	0.783	2.133	2.178	2.149	0.448
ST03W04C	370	0.820	0.639	0.691	0.715	2.048	2.207	2.213	0.419
ST03W05A	445	0.885	0.698	0.753	0.803	2.226	2.187	2.143	0.466
ST03W05B	520	0.840	0.680	0.738	0.774	2.226	2.192	2.153	0.472
ST03W05C	595	0.937	0.730	0.798	0.848	2.133	2.186	2.132	0.518
ST03W05D	670	0.895	0.713	0.799	0.843	2.133	2.200	2.171	0.508
ST03W05E	750	0.901	0.710	0.801	0.886	2.226	2.192	2.157	0.529
ST03W06A	825	0.877	0.709	0.808	0.877	2.327	2.188	2.155	0.530
ST03W06B	900	0.854	0.691	0.804	0.913	2.048	2.185	2.140	0.516
ST03W06C	975	0.924	0.747	0.808	0.837	2.226	2.196	2.177	0.513
ST03W06D	1050	0.886	0.720	0.773	0.830	2.226	2.196	2.187	0.518
ST03W06E	1125	0.887	0.708	0.842	0.896	2.226	2.195	2.166	0.534
ST03W06F	1200	0.977	0.776	0.877	0.954	2.048	2.188	2.159	0.541
ST03W06G	1275	0.937	0.740	0.823	0.865	2.133	2.183	2.166	0.560
ST03W06H	1350	0.891	0.714	0.798	0.855	2.133	2.186	2.157	0.531
ST03W06I	1425	0.909	0.728	0.806	0.847	2.327	2.190	2.168	0.528
ST03W06J	1450			No Data Recorded					
ST03W07A	1525	0.911	0.727	0.812	0.841	2.226	2.189	2.176	0.520
ST03W07B	1600	0.912	0.720	0.819	0.875	2.133	2.184	2.140	0.533
ST03W07C	1650			No Data Recorded					
ST03W08	1850	0.867	0.704	0.820	0.871	2.226	2.200	2.166	0.539
Averages		0.884	0.702	0.787	0.836	2.193	2.191	2.168	0.504

Table B4. Test T04

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST04W01	40	1.021	0.738	0.777	0.841	2.327	2.204	2.213	0.077
ST04W02	80	1.008	0.703	0.727	0.732	2.327	2.198	2.213	0.080
ST04W03	170	1.030	0.748	0.900	0.977	2.226	2.210	2.222	0.218
ST04W04A	245	1.045	0.762	0.815	0.867	2.226	2.199	2.202	0.082
ST04W04B	320	0.983	0.687	0.729	0.759	2.226	2.202	2.020	0.109
ST04W04C	370			No Data Recorded					
ST04W05A	445	0.918	0.621	0.668	0.717	2.226	2.201	2.195	0.159
ST04W05B	520	0.993	0.695	0.759	0.795	2.226	2.204	2.193	0.150
ST04W05C	595	0.979	0.675	0.755	0.819	2.327	2.203	2.197	0.163
ST04W05D	670	0.996	0.700	0.794	0.835	2.226	2.204	2.191	0.161
ST04W05E	750	0.947	0.643	0.714	0.766	2.226	2.206	2.196	0.198
ST04W06A	825	0.886	0.589	0.646	0.680	2.226	2.201	2.186	0.213
ST04W06B	900	0.906	0.611	0.673	0.709	2.226	2.201	2.190	0.199
ST04W06C	975	0.974	0.680	0.775	0.830	2.327	2.199	2.192	0.189
ST04W06D	1050	0.999	0.693	0.801	0.865	2.226	2.202	2.207	0.189
ST04W06E	1125	1.033	0.733	0.827	0.876	2.327	2.205	2.198	0.182
ST04W06F	1200	0.890	0.595	0.665	0.695	2.327	2.195	2.199	0.217
ST04W06G	1275	0.984	0.681	0.780	0.839	2.226	2.203	2.203	0.190
ST04W06H	1350	0.941	0.658	0.761	0.819	2.226	2.201	2.194	0.199
ST04W06I	1425	0.936	0.638	0.729	0.775	2.226	2.201	2.198	0.200
ST04W06J	1450			No Data Recorded					
ST04W07A	1525	0.962	0.669	0.771	0.838	2.327	2.202	2.189	0.196
ST04W07B	1600	0.967	0.676	0.765	0.850	2.226	2.201	2.191	0.195
St04W07C	1650			No Data Recorded					
ST04W08	1850	0.954	0.653	0.750	0.825	2.226	2.202	2.213	0.173
<u>Averages</u>									
		0.968	0.672	0.753	0.803	2.255	2.204	2.190	0.174

(Continued)

Table B4 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	HL/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	TL/3 (sec)	Reflect. Coeff.
<b>Nearshore Wave Gage Averages</b>									
ST04W01	40	0.854	0.629	0.682	0.723	2.226	2.195	2.194	0.470
ST04W02	80	0.944	0.761	0.828	0.883	2.133	2.201	2.208	0.531
ST04W03	170	0.951	0.755	0.889	0.969	2.133	2.183	2.233	0.502
ST04W04A	245	0.944	0.735	0.785	0.825	2.133	2.181	2.152	0.462
ST04W04B	320	0.902	0.715	0.774	0.847	2.226	2.199	2.138	0.458
ST04W04C	370				No Data Recorded				
ST04W05A	445	0.932	0.733	0.787	0.855	2.226	2.183	2.177	0.475
ST04W05B	520	0.973	0.765	0.838	0.908	2.113	2.169	2.123	0.502
ST04W05C	595	0.911	0.714	0.802	0.867	2.133	2.171	2.126	0.511
ST04W05D	670	0.996	0.753	0.850	0.915	2.226	2.181	2.110	0.531
ST04W05E	750	0.899	0.697	0.780	0.854	2.226	2.197	2.164	0.507
ST04W06A	825	0.852	0.689	0.734	0.766	2.226	2.187	2.173	0.426
ST04W06B	900	0.901	0.710	0.780	0.829	2.438	2.187	2.158	0.465
ST04W06C	975	0.918	0.710	0.793	0.828	2.226	2.183	2.170	0.494
ST04W06D	1050	0.944	0.715	0.823	0.915	2.133	2.176	2.141	0.534
ST04W06E	1125	0.907	0.697	0.836	0.894	2.226	2.185	2.123	0.511
ST04W06F	1200	0.910	0.699	0.805	0.843	2.327	2.196	2.185	0.463
ST04W06G	1275	0.951	0.725	0.820	0.907	2.133	2.173	2.137	0.530
ST04W06H	1350	1.010	0.761	0.851	0.919	2.048	2.169	2.145	0.524
ST04W06I	1425	0.893	0.694	0.778	0.823	2.133	2.182	2.162	0.478
ST04W06J	1450				No Data Recorded				
ST04W07A	1525	0.940	0.742	0.803	0.844	2.133	2.169	2.152	0.477
ST04W07B	1600	0.934	0.710	0.816	0.874	2.226	2.191	2.161	0.504
ST04W07C	1650				No Data Recorded				
ST04W08	1850	0.852	0.668	0.752	0.797	2.226	2.216	2.222	0.438
Averages		0.924	0.717	0.800	0.858	2.193	2.185	2.162	0.491

Table B5. Test T05

Filename	Total Waves	Hmo (ft)	Hbar (ft)	HL/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
ST05W01	40								
ST05W02	80								
ST05W03	170								
ST05W04A	245								
ST05W04B	320								
ST05W04C	370								
ST05W05A	445								
ST05W05B	520								
ST05W05C	595								
ST05W05D	670								
ST05W05E	750								
ST05W06A	825								
ST05W06B	900								
ST05W06C	975								
ST05W06D	1050								
ST05W06E	1125								
ST05W06F	1200								
ST05W06G	1275								
ST05W06H	1350								
ST05W06I	1425								
ST05W06J	1450								
ST05W07A	1525								
ST05W07B	1600								
ST05W07C	1650								
ST05W08	1850								
Data Recorded But Not Analyzed at This Time									
Averages									

Table B6. Test T06

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
Profile Molded to Match Prototype									
ST06W02	40	0.870	0.583	0.638	0.662	2.327	2.197	2.211	0.155
ST06W03	80	0.905	0.646	0.724	0.761	2.133	2.201	2.200	0.106
ST06W04A	170	0.918	0.648	0.771	0.887	2.194	2.198	2.202	0.195
ST06W04B	245	0.940	0.675	0.801	0.904	2.156	2.199	2.207	0.168
ST06W04C	320								
ST06W05A	370								
ST06W05B	445	0.888	0.647	0.689	0.719	2.194	2.201	2.201	0.085
ST06W05C	520	0.893	0.630	0.695	0.778	2.194	2.200	2.201	0.086
ST06W05D	595	0.883	0.624	0.680	0.750	2.194	2.200	2.201	0.077
ST06W05E	670	0.873	0.616	0.660	0.692	2.194	2.201	2.201	0.077
ST06W06A	750	0.869	0.611	0.654	0.685	2.194	2.200	2.200	0.079
ST06W06B	825	0.860	0.598	0.640	0.664	2.194	2.200	2.201	0.085
ST06W06C	900	0.860	0.597	0.637	0.662	2.194	2.200	2.201	0.083
ST06W06D	975	0.859	0.598	0.643	0.665	2.194	2.199	2.200	0.087
ST06W06E	1050	0.864	0.599	0.648	0.691	2.194	2.200	2.200	0.090
ST06W06F	1125	0.855	0.593	0.634	0.686	2.194	2.200	2.201	0.098
ST06W06G	1200	0.859	0.596	0.648	0.685	2.194	2.200	2.201	0.094
ST06W06H	1275	0.852	0.587	0.628	0.662	2.194	2.200	2.200	0.098
ST06W06I	1350	0.853	0.589	0.630	0.660	2.194	2.199	2.200	0.098
ST06W06J	1425	0.856	0.590	0.634	0.657	2.194	2.200	2.201	0.100
ST06W07A	1450								
ST06W07B	1525	0.860	0.595	0.637	0.659	2.194	2.200	2.201	0.093
ST06W07C	1600	0.857	0.594	0.630	0.658	2.194	2.200	2.201	0.093
ST06W08	1850	0.842	0.576	0.593	0.605	2.327	2.198	2.201	0.106
Averages									
		0.874	0.611	0.668	0.713	2.202	2.200	2.202	0.107

(Continued)

Table B6 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
Profile Molded to Match Prototype									
	40								
ST06W02	80	0.864	0.699	0.781	0.803	2.226	2.165	2.201	0.674
ST06W03	170	0.783	0.608	0.668	0.722	2.276	2.199	2.184	0.397
ST06W04A	245	0.806	0.619	0.740	0.858	2.234	2.199	2.178	0.487
ST06W04B	320	0.837	0.635	0.740	0.829	2.234	2.199	2.181	0.467
ST06W04C	370								
Data Not Recorded									
ST06W05A	445	0.799	0.610	0.649	0.706	2.156	2.201	2.200	0.398
ST06W05B	520	0.814	0.626	0.681	0.719	2.234	2.199	2.187	0.455
ST06W05C	595	0.826	0.631	0.690	0.734	2.234	2.200	2.161	0.458
ST06W05D	670	0.803	0.622	0.675	0.715	2.156	2.200	2.177	0.433
ST06W05E	750	0.812	0.631	0.681	0.718	2.234	2.200	2.178	0.430
ST06W06A	825	0.808	0.620	0.666	0.694	2.194	2.200	2.186	0.421
ST06W06B	900	0.807	0.626	0.672	0.719	2.194	2.199	2.182	0.427
ST06W06C	975	0.806	0.623	0.666	0.718	2.234	2.201	2.178	0.439
ST06W06D	1050	0.817	0.632	0.675	0.728	2.234	2.200	2.186	0.433
ST06W06E	1125	0.818	0.633	0.682	0.728	2.234	2.201	2.181	0.439
ST06W06F	1200	0.821	0.637	0.689	0.737	2.234	2.201	2.184	0.434
ST06W06G	1275	0.812	0.629	0.671	0.703	2.234	2.201	2.189	0.441
ST06W06H	1350	0.803	0.622	0.664	0.694	2.156	2.200	2.176	0.441
ST06W06I	1425	0.812	0.627	0.674	0.730	2.194	2.201	2.167	0.452
Data Not Recorded									
ST06W06J	1450								
ST06W07A	1525	0.816	0.637	0.683	0.729	2.194	2.200	2.179	0.432
ST06W07B	1600	0.821	0.639	0.684	0.719	2.194	2.201	2.171	0.449
ST06W07C	1650								
Data Not Recorded									
ST06W08		0.801	0.615	0.651	0.676	2.226	2.195	2.209	0.466
<u>Averages</u>									
		0.813	0.629	0.687	0.738	2.215	2.198	2.182	0.453



Table B7. Test T07

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST07W01	40	1.037	0.721	0.734	0.752	2.226	1.998	2.003	0.085
ST07W02	80	1.046	0.730	0.738	0.748	1.969	2.001	2.001	0.081
ST07W03	170	1.070	0.754	0.830	0.937	1.991	2.000	2.007	0.147
ST07W04A	252	1.056	0.741	0.764	0.792	2.048	2.000	1.998	0.081
ST07W04B	334	1.056	0.741	0.785	0.844	2.014	2.001	2.003	0.114
ST07W04C	370			Data Not Recorded					
ST07W05A	452	1.030	0.712	0.767	0.794	2.014	2.000	2.001	0.146
ST07W05B	534	1.061	0.732	0.786	0.830	2.014	2.000	2.005	0.138
ST07W05C	616	1.041	0.720	0.781	0.829	2.014	2.000	2.004	0.151
ST07W05D	698	1.064	0.738	0.811	0.882	2.048	2.000	2.012	0.150
ST07W05E	750			Data Not Recorded					
ST07W06A	832	0.843	0.569	0.656	0.679	2.194	2.198	2.202	0.175
ST07W06B	914	1.044	0.716	0.774	0.805	2.014	2.001	2.004	0.158
ST07W06C	996	1.056	0.729	0.793	0.844	2.014	2.000	2.005	0.162
ST07W06D	1078	1.026	0.715	0.784	0.822	2.014	2.001	2.004	0.176
ST07W06E	1160	1.031	0.717	0.787	0.827	2.014	2.001	2.005	0.173
ST07W06F	1242	1.042	0.724	0.802	0.852	2.014	2.000	2.009	0.176
ST07W06G	1324	1.031	0.717	0.787	0.827	2.014	2.000	2.003	0.175
ST07W06H	1406	1.020	0.715	0.784	0.836	2.014	2.001	2.001	0.167
ST07W06I	1450			Data Not Recorded					
ST07W07A	1532	1.063	0.738	0.817	0.911	1.982	2.001	2.011	0.164
ST07W07B	1614	1.054	0.729	0.808	0.887	2.048	2.000	2.013	0.167
ST07W07C	1650			Data Not Recorded					
ST07W08A	1850	1.043	0.729	0.822	0.924	2.008	2.000	2.008	0.194
Averages		1.036	0.719	0.781	0.831	2.033	2.010	2.015	0.149

(Continued)

Table B7 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST07W01	40	0.923	0.697	0.843	0.875	1.969	2.007	1.990	0.599
ST07W02	80	0.872	0.603	0.720	0.792	1.896	2.018	1.995	0.451
ST07W03	170	0.942	0.706	0.791	0.864	1.991	1.999	1.999	0.477
ST07W04A	252	0.974	0.715	0.764	0.810	2.014	1.992	1.981	0.470
ST07W04B	334	0.939	0.715	0.788	0.844	1.982	1.994	2.004	0.452
ST07W04C	370			Data Not Recorded					
ST07W05A	452	1.023	0.725	0.784	0.826	1.982	1.996	2.006	0.540
ST07W05B	534	0.974	0.728	0.798	0.854	1.950	1.995	2.010	0.481
ST07W05C	616	0.981	0.735	0.821	0.891	1.982	1.996	2.021	0.490
ST07W05D	698	0.978	0.734	0.825	0.896	1.950	1.993	2.017	0.512
ST07W05E	750			Data Not Recorded					
ST07W06A	832	0.827	0.661	0.723	0.766	2.156	2.194	2.168	0.502
ST07W06B	914	1.004	0.718	0.770	0.828	1.950	1.994	2.000	0.531
ST07W06C	996	0.982	0.729	0.796	0.864	1.950	1.996	2.004	0.506
ST07W06D	1078	0.972	0.722	0.792	0.837	1.920	1.995	1.996	0.511
ST07W06E	1160	0.999	0.735	0.808	0.878	2.014	1.995	2.006	0.523
ST07W06F	1242	1.022	0.764	0.844	0.923	2.014	1.995	2.010	0.521
ST07W06G	1324	0.983	0.749	0.827	0.897	2.014	1.996	2.004	0.514
ST07W06H	1406	0.985	0.728	0.811	0.866	1.920	1.995	2.004	0.533
ST07W06I	1450			Data Not Recorded					
ST07W07A	1532	0.996	0.742	0.838	0.909	1.950	1.994	2.013	0.558
ST07W07B	1614	1.024	0.766	0.869	0.967	1.982	1.996	2.011	0.565
ST07W07C	1650			Data Not Recorded					
ST07W08A	1850	0.926	0.731	0.832	0.935	1.969	1.989	2.002	0.470
Averages		0.966	0.720	0.802	0.866	1.978	2.006	2.012	0.510

Table B8. Test T08

Filename	Total Waves	Hmo (ft)	Hbar (ft)	HL/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST08W01	40	0.981	0.617	0.935	1.300	2.133	1.893	2.100	0.181
ST08W02	80	1.004	0.642	0.916	1.213	2.133	1.955	2.097	0.148
ST08W03	170	1.001	0.631	0.938	1.267	2.207	1.947	2.071	0.265
ST08W04A	270	1.002	0.632	0.940	1.281	2.207	1.947	2.078	0.306
ST08W04B	370	0.980	0.644	0.947	1.344	2.246	1.997	2.092	0.135
ST08W05A	465	0.969	0.637	0.929	1.303	2.246	2.002	2.071	0.132
ST08W05B	560	1.001	0.646	0.939	1.284	2.246	1.989	2.054	0.197
ST08W05C	655	0.973	0.648	0.942	1.163	2.246	2.020	2.079	0.286
ST08W05D	750	1.016	0.641	0.924	1.294	2.246	2.016	2.143	0.423
ST08W06A	845	0.984	0.651	0.928	1.212	2.246	2.048	2.084	0.254
ST08W06B	940	1.002	0.656	0.930	1.245	2.246	2.061	2.103	0.333
ST08W06C	1035	1.009	0.652	0.938	1.336	2.246	1.995	2.083	0.249
ST08W06D	1130	1.011	0.646	0.939	1.191	2.246	2.030	2.151	0.407
ST08W06E	1225	0.985	0.628	0.924	1.279	2.246	1.956	2.057	0.258
ST08W06F	1320	1.000	0.626	0.923	1.238	2.133	1.963	2.093	0.367
ST08W06G	1415	0.988	0.649	0.943	1.319	2.207	1.998	2.069	0.350
ST08W06H	1450	No Data Recorded							
ST08W07A	1550	0.983	0.637	0.927	1.310	2.246	1.994	2.083	0.256
ST08W07B	1650	0.967	0.642	0.925	1.300	2.133	2.050	2.113	0.350
Averages		0.992	0.640	0.933	1.271	2.214	1.992	2.090	0.272

(Continued)

Table B8 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST08W01	40	0.728	0.524	0.801	1.081	2.240	2.002	2.133	0.575
ST08W02	80	0.792	0.515	0.793	1.036	2.240	1.930	2.078	0.607
ST08W03	170	0.783	0.516	0.778	1.063	2.246	1.960	2.151	0.504
ST08W04A	270	0.822	0.526	0.809	1.086	2.246	1.938	2.118	0.506
ST08W04B	370	0.761	0.535	0.787	1.052	2.327	2.098	2.173	0.471
ST08W05A	465	0.787	0.531	0.785	1.092	2.246	1.985	2.175	0.484
ST08W05B	560	0.799	0.539	0.779	1.107	2.246	2.031	2.153	0.470
ST08W05C	655	0.739	0.521	0.746	1.007	2.169	2.074	2.165	0.466
ST08W05D	750	0.794	0.539	0.801	1.093	2.246	2.018	2.147	0.459
ST08W06A	845	0.797	0.534	0.785	1.137	2.415	2.006	2.250	0.502
ST08W06B	940	0.783	0.534	0.816	1.055	2.286	2.015	2.168	0.467
ST08W06C	1035	0.791	0.543	0.812	1.144	2.370	2.112	2.297	0.483
ST08W06D	1130	0.754	0.526	0.777	1.100	2.246	2.058	2.178	0.458
ST08W06E	1225	0.799	0.538	0.788	1.113	2.286	2.037	2.144	0.485
ST08W06F	1320	0.819	0.536	0.790	1.107	2.286	1.984	2.161	0.523
ST08W06G	1415	0.812	0.533	0.816	1.084	2.246	1.973	2.109	0.487
ST08W06H	1450			No Data Recorded					
ST08W07A	1550	0.783	0.527	0.781	1.121	2.286	1.963	2.178	0.494
ST08W07B	1650	0.797	0.539	0.781	1.121	2.286	2.003	2.108	0.499
Averages		0.786	0.531	0.790	1.089	2.273	2.010	2.160	0.497

Table B9. Test T09

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
Offshore Wave Gage Averages									
ST09W01A	40	0.809	0.535	0.775	1.082	2.084	1.938	2.016	0.182
ST09W02	80	0.782	0.505	0.738	1.054	2.084	1.903	1.995	0.139
ST09W03	170	0.768	0.507	0.764	1.122	2.169	1.873	1.970	0.180
ST09W04A	270	0.780	0.510	0.774	1.108	2.169	1.864	1.963	0.159
ST09W04B	370	0.774	0.534	0.788	1.078	2.169	1.929	2.022	0.167
ST09W05A	465	0.759	0.498	0.753	1.090	2.169	1.871	2.018	0.154
ST09W05B	560	0.764	0.531	0.774	1.072	2.169	1.951	2.044	0.160
ST09W05C	655	0.764	0.497	0.758	1.087	2.169	1.893	2.009	0.145
ST09W05D	750	0.763	0.488	0.751	1.092	2.169	1.827	2.024	0.164
ST09W06A	845	0.760	0.510	0.764	1.073	2.169	1.909	2.015	0.146
ST09W06B	940	0.756	0.494	0.744	1.066	2.169	1.873	2.015	0.154
ST09W06C	1035	0.752	0.510	0.756	1.058	2.169	1.941	2.050	0.147
ST09W06D	1130	0.766	0.505	0.763	1.076	2.169	1.882	2.030	0.149
ST09W06E	1225	0.753	0.516	0.756	1.082	2.169	1.959	1.981	0.146
ST09W06F	1320	0.744	0.493	0.740	1.071	2.169	1.892	2.054	0.146
ST09W06G	1415	0.767	0.516	0.770	1.072	2.169	1.902	2.015	0.144
ST09W06H	1450				No Data Recorded				
ST09W07A	1550	0.768	0.514	0.773	1.095	2.169	1.901	2.084	0.158
ST09W07B	1650	0.850	0.569	0.785	1.058	2.036	1.953	1.979	0.094
ST09W08A	1750	0.775	0.516	0.776	1.118	2.169	1.910	2.050	0.151
ST09W08B	1850	0.784	0.506	0.764	1.062	2.169	1.845	2.011	0.174
Averages		0.772	0.513	0.763	1.081	2.154	1.901	2.017	0.153

(Continued)

Table B9 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST09W01A	40	0.700	0.500	0.722	0.884	2.358	2.026	2.186	0.534
ST09W02	80	0.688	0.488	0.697	0.939	2.358	2.028	2.151	0.489
ST09W03	170	0.729	0.506	0.725	0.928	2.133	1.955	2.090	0.516
ST09W04A	270	0.730	0.508	0.729	0.969	2.133	1.985	2.057	0.497
ST09W04B	370	0.727	0.500	0.720	0.916	2.133	1.965	2.082	0.495
ST09W05A	465	0.728	0.514	0.720	1.041	2.327	2.039	2.066	0.486
ST09W05B	560	0.723	0.497	0.701	0.934	2.169	1.988	2.167	0.495
ST09W05C	655	0.737	0.520	0.726	0.888	2.133	2.005	2.070	0.495
ST09W05D	750	0.714	0.498	0.702	0.931	2.246	1.949	2.007	0.483
ST09W06A	845	0.738	0.516	0.713	0.999	2.133	2.036	2.106	0.502
ST09W06B	940	0.733	0.503	0.708	0.954	2.133	1.971	2.095	0.488
ST09W06C	1035	0.727	0.501	0.700	0.947	2.098	1.989	2.083	0.488
ST09W06D	1130	0.745	0.515	0.723	0.930	2.098	1.990	2.075	0.498
ST09W06E	1225	0.728	0.494	0.709	0.940	2.098	1.937	2.034	0.508
ST09W06F	1320	0.732	0.493	0.696	0.926	2.133	1.942	2.058	0.509
ST09W06G	1415	0.722	0.500	0.705	0.882	2.246	1.969	2.058	0.482
ST09W06H	1450			Data Not Recorded					
ST09W07A	1550	0.738	0.514	0.715	0.930	2.098	1.995	2.107	0.518
ST09W07B	1650	0.582	0.446	0.648	0.833	2.358	2.217	2.142	0.450
ST09W08A	1750	0.741	0.511	0.713	0.920	2.133	1.955	2.075	0.503
ST09W08B	1850	0.745	0.520	0.740	1.130	2.370	1.972	2.094	0.501
Averages		0.720	0.502	0.711	0.941	2.194	1.996	2.090	0.497

Table B10. Test T10

Filename	Total Waves	Hmo (ft)	Hbar (ft)	HL/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
Offshore Wave Gage Averages									
ST10W01	40	0.886	0.636	0.664	0.711	2.327	2.202	2.207	0.063
ST10W02	80	0.891	0.638	0.666	0.745	2.327	2.200	2.207	0.070
ST10W03	170	0.999	0.762	0.864	0.926	2.276	2.200	2.209	0.182
ST10W04A	245	0.960	0.726	0.810	0.859	2.194	2.201	2.210	0.141
ST10W04B	320	0.980	0.737	0.827	0.881	2.156	2.200	2.208	0.152
ST10W04C	370				No Data Recorded				
ST10W05A	445	0.973	0.736	0.836	0.893	2.156	2.200	2.208	0.157
ST10W05B	520	0.977	0.739	0.844	0.915	2.156	2.200	2.203	0.164
ST10W05C	595	0.974	0.729	0.855	0.941	2.156	2.200	2.207	0.176
ST10W05D	670	0.966	0.710	0.834	0.978	2.156	2.201	2.229	0.183
ST10W05E	750	0.918	0.685	0.800	0.934	2.194	2.200	2.198	0.192
ST10W06A	825	1.008	0.777	0.871	0.908	2.194	2.200	2.201	0.166
ST10W06B	900	0.951	0.715	0.835	0.935	2.194	2.201	2.204	0.190
ST10W06C	975	0.999	0.766	0.875	0.939	2.156	2.199	2.206	0.185
ST10W06D	1050	0.949	0.714	0.836	0.950	2.194	2.202	2.212	0.192
ST10W06E	1125	0.979	0.745	0.863	0.960	2.156	2.200	2.202	0.186
ST10W06F	1200	0.977	0.745	0.876	0.994	2.194	2.200	2.213	0.187
ST10W06G	1275	0.958	0.708	0.835	0.954	2.156	2.199	2.203	0.192
ST10W06H	1350				No Data Recorded				
ST10W06I	1425	0.907	0.662	0.767	0.878	2.234	2.203	2.212	0.195
ST10W06J	1450				No Data Recorded				
ST10W07A	1525	0.973	0.743	0.861	0.957	2.194	2.200	2.211	0.185
ST10W07B	1600	0.978	0.750	0.873	0.992	2.194	2.200	2.201	0.178
ST10W07C	1650				No Data Recorded				
Averages		0.960	0.721	0.825	0.912	2.198	2.200	2.208	0.167

(Continued)

Table B10 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
STLOW01	40	0.731	0.539	0.593	0.630	2.133	2.183	2.184	0.450
STLOW02	80	0.827	0.680	0.730	0.764	2.327	2.189	2.196	0.476
STLOW03	170	0.889	0.723	0.821	0.921	2.101	2.194	2.225	0.489
STLOW04A	245	0.851	0.689	0.778	0.863	2.318	2.191	2.222	0.479
STLOW04B	320	0.874	0.705	0.812	0.899	2.318	2.191	2.222	0.499
STLOW04C	370			No Data Recorded					
STLOW05A	445	0.889	0.721	0.827	0.924	2.234	2.203	2.219	0.513
STLOW05B	520	0.894	0.723	0.836	0.939	2.234	2.200	2.213	0.517
STLOW05C	595	0.881	0.711	0.828	0.915	2.318	2.200	2.230	0.514
STLOW05D	670	0.881	0.711	0.826	0.952	2.276	2.199	2.229	0.531
STLOW05E	750	0.839	0.672	0.792	0.944	2.318	2.203	2.240	0.504
STLOW06A	825	0.892	0.747	0.847	0.945	2.234	2.195	2.193	0.523
STLOW06B	900	0.867	0.720	0.835	0.945	2.234	2.203	2.211	0.519
STLOW06C	975	0.914	0.740	0.869	0.996	2.234	2.197	2.200	0.545
STLOW06D	1050	0.869	0.710	0.831	0.933	2.276	2.203	2.219	0.525
STLOW06E	1125	0.883	0.710	0.843	0.966	2.276	2.183	2.194	0.518
STLOW06F	1200	0.872	0.708	0.821	0.972	2.318	2.200	2.200	0.508
STLOW06G	1275	0.858	0.694	0.817	0.950	2.318	2.192	2.195	0.522
STLOW06H	1350			No Data Recorded					
STLOW06I	1425	0.838	0.689	0.812	0.910	2.318	2.195	2.211	0.506
STLOW06J	1450			No Data Recorded					
STLOW07A	1525	0.891	0.725	0.836	0.970	2.194	2.202	2.207	0.518
STLOW07B	1600	0.886	0.721	0.836	0.959	2.234	2.188	2.175	0.537
STLOW07C	1650			No Data Recorded					
Averages		0.866	0.702	0.790	0.915	2.261	2.196	2.209	0.510



Table B11. Test T11

Filename	Total Waves	Hmo (ft)	Hbar (ft)	HL/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
<u>Offshore Wave Gage Averages</u>									
ST11W01	40	0.857	0.604	0.864	1.066	2.084	2.026	2.033	0.244
ST11W02	80	0.772	0.505	0.721	1.058	2.084	1.952	1.985	0.153
ST11W03	170	0.806	0.532	0.786	1.169	2.134	1.948	2.007	0.179
ST11W04A	270	0.757	0.481	0.722	1.099	2.212	1.835	2.005	0.172
ST11W04B	370	0.748	0.472	0.711	1.038	2.212	1.808	1.988	0.157
ST11W05A	465	0.767	0.492	0.732	1.070	2.212	1.841	2.002	0.160
ST11W05B	560	0.760	0.493	0.732	1.065	2.212	1.879	2.013	0.165
ST11W05C	655	0.763	0.494	0.732	1.024	2.212	1.839	1.979	0.155
ST11W05D	750	0.756	0.477	0.727	1.013	2.212	1.834	2.078	0.172
ST11W06A	926	0.766	0.492	0.728	1.030	2.212	1.860	1.985	0.170
ST11W06B	1035	0.763	0.488	0.730	1.089	2.212	1.835	2.049	0.183
ST11W06C	1236	0.780	0.500	0.748	1.124	2.084	1.874	1.992	0.194
ST11W06D	1450	0.786	0.500	0.753	1.092	2.084	1.862	1.985	0.203
ST11W07A	1543	0.769	0.498	0.736	1.067	2.212	1.839	1.971	0.203
ST11W07B	1650	0.760	0.487	0.725	0.953	2.212	1.833	1.993	0.217
ST11W08	1850	0.799	0.504	0.770	1.158	2.084	1.827	1.958	0.220
Averages		0.776	0.501	0.745	1.070	2.167	1.868	2.001	0.184

(Continued)

Table B11 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST11W01	40	0.705	0.533	0.776	0.962	2.422	2.116	2.281	0.612
ST11W02	80	0.700	0.494	0.705	0.936	2.358	2.050	2.213	0.532
ST11W03	170	0.724	0.520	0.746	0.961	2.270	2.026	2.130	0.511
ST11W04A	270	0.709	0.495	0.701	0.948	2.108	1.963	2.128	0.503
ST11W04B	370	0.699	0.495	0.694	0.991	2.133	1.969	2.075	0.496
ST11W05A	465	0.699	0.495	0.694	0.959	2.240	1.995	2.111	0.486
ST11W05B	560	0.692	0.505	0.687	0.941	2.240	2.038	2.038	0.481
ST11W05C	655	0.713	0.498	0.697	0.927	2.185	1.972	2.095	0.497
ST11W05D	750	0.702	0.481	0.690	0.973	2.240	1.891	2.002	0.490
ST11W06A	926	0.696	0.494	0.696	0.962	2.240	1.983	2.079	0.482
ST11W06B	1035	0.704	0.510	0.709	0.944	2.240	2.026	2.126	0.488
ST11W06C	1236	0.689	0.491	0.698	0.988	2.283	1.960	2.119	0.497
ST11W06D	1450	0.702	0.506	0.715	1.008	2.283	1.998	2.091	0.499
ST11W07A	1543	0.721	0.508	0.719	0.998	2.240	1.942	2.059	0.517
ST11W07B	1650	0.722	0.515	0.733	0.969	2.212	1.979	2.034	0.527
ST11W08	1850	0.734	0.519	0.745	1.126	2.283	1.929	2.139	0.507
Averages		0.707	0.504	0.713	0.975	2.249	1.990	2.108	0.508

Table B12. Test T12

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
ST05W01	40								
ST05W02	80								
ST05W03	170								
ST05W04A	245								
ST05W04B	320								
ST05W04C	370								
ST05W05A	445								
ST05W05B	520								
ST05W05C	595								
ST05W05D	670								
ST05W05E	750								
ST05W06A	825								
ST05W06B	900								
ST05W06C	975								
ST05W06D	1050								
ST05W06E	1125								
ST05W06F	1200								
ST05W06G	1275								
ST05W06H	1350								
ST05W06I	1425								
ST05W06J	1450								
ST05W07A	1525								
ST05W07B	1600								
ST05W07C	1650								
ST05W08	1850								
Data Recorded But Not Analyzed at This Time									
Averages									

Table B13. Test T13

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
ST05W01	40								
ST05W02	80								
ST05W03	170								
ST05W04A	245								
ST05W04B	320								
ST05W04C	370								
ST05W05A	445								
ST05W05B	520								
ST05W05C	595								
ST05W05D	670								
ST05W05E	750								
ST05W06A	825								
ST05W06B	900								
ST05W06C	975								
ST05W06D	1050								
ST05W06E	1125								
ST05W06F	1200								
ST05W06G	1275								
ST05W06H	1350								
ST05W06I	1425								
ST05W06J	1450								
ST05W07A	1525								
ST05W07B	1600								
ST05W07C	1650								
ST05W08	1850								
Data Recorded But Not Analyzed at This Time									
Averages									

Table B14. Test T14

Filename	Number Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
Offshore Wave Gage Averages									
ST14W01	34	0.543	0.330	0.490	0.643	2.055	1.774	1.979	0.187
ST14W02	33	0.601	0.378	0.554	0.767	2.123	1.836	2.024	0.104
ST14W03A	33	0.620	0.344	0.565	0.680	2.000	1.811	1.028	0.097
ST14W03B	86	0.680	0.408	0.627	0.955	2.162	1.834	2.074	0.176
ST14W04A	137	0.663	0.420	0.634	1.208	2.222	1.870	2.068	0.207
ST14W04B	84	0.691	0.432	0.645	0.968	2.162	1.871	2.076	0.180
ST14W05A	83	0.735	0.462	0.685	1.048	2.162	1.900	2.098	0.176
ST14W05B	143	0.701	0.457	0.685	1.047	2.218	1.924	2.083	0.193
ST14W06A	101	0.687	0.440	0.661	0.980	2.188	1.897	2.077	0.185
ST14W06B	86	0.722	0.461	0.678	0.937	2.179	1.973	2.063	0.149
ST14W06C				No Data Recorded					
ST14W06D				No Data Recorded					
ST14W07A	77	0.733	0.463	0.679	0.928	2.239	1.928	2.094	0.132
ST14W07B	101	0.726	0.482	0.703	1.019	2.198	1.966	2.090	0.136
ST14W07C	101	0.748	0.495	0.719	1.007	2.198	1.972	2.097	0.142
ST14W07D	100	0.749	0.494	0.722	1.027	2.198	1.979	2.070	0.145
ST14W08A	66	0.756	0.475	0.700	0.965	2.215	1.933	2.082	0.153
ST14W08B	91	0.754	0.467	0.687	0.980	2.160	1.918	2.085	0.138
ST14W08C	102	0.755	0.489	0.715	0.985	2.198	1.939	2.063	0.153
ST14W08D	89	0.774	0.486	0.714	0.998	2.303	1.951	2.097	0.144
ST14W09A	103	0.762	0.495	0.723	1.002	2.198	1.946	2.082	0.153
ST14W09B	101	0.776	0.506	0.741	0.989	2.198	1.953	2.103	0.153
ST14W09C	84	0.785	0.499	0.728	1.017	2.171	1.954	2.087	0.144
ST14W09D	103	0.786	0.506	0.746	1.053	2.198	1.927	2.084	0.147
ST14W09E				No Data Recorded					
ST14W10A	101	0.677	0.444	0.653	0.918	2.198	1.966	2.090	0.163
ST14W10B	103	0.696	0.450	0.667	0.908	2.198	1.939	2.089	0.164
ST14W10C	100	0.704	0.467	0.680	0.910	2.198	1.991	2.088	0.163

(Continued)

(Sheet 1 of 4)

Table B14 (Continued)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	H1/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
ST14W10D	103	0.695	0.448	0.567	0.881	2.198	1.934	2.089	0.162
ST14W10E				No Data Recorded					
ST14W11A	99	0.725	0.478	0.696	0.976	2.198	1.992	2.079	0.153
ST14W11B	103	0.723	0.436	0.695	0.959	2.198	1.921	2.071	0.154
ST14W11C	105	0.725	0.458	0.688	0.930	2.198	1.897	2.077	0.150
ST14W11D	66	0.721	0.461	0.684	0.914	2.241	1.936	2.091	0.132
ST14W11E				No Data Recorded					
ST14W12A	104	0.732	0.472	0.703	0.950	2.198	1.909	2.075	0.157
ST14W12B	103	0.741	0.477	0.708	0.960	2.198	1.915	2.091	0.160
ST14W12C	104	0.737	0.466	0.702	0.903	2.198	1.903	2.067	0.153
ST14W12D	66	0.756	0.475	0.705	1.051	2.241	1.925	2.154	0.134
ST14W12E				No Data Recorded					
ST14W13A	100	0.698	0.458	0.670	0.942	2.198	1.980	2.097	0.159
ST14W13B	102	0.713	0.458	0.681	0.955	2.198	1.929	2.109	0.160
ST14W13C	104	0.705	0.450	0.670	0.938	2.198	1.929	2.091	0.158
ST14W13D	102	0.729	0.476	0.698	0.991	2.198	1.959	2.071	0.150
ST14W13E	103	0.736	0.470	0.699	1.000	2.198	1.922	2.077	0.156
ST14W13F	66	0.719	0.462	0.680	0.923	2.241	1.933	2.082	0.132
ST14W14A	104	0.725	0.462	0.690	0.902	2.198	1.909	2.076	0.152
ST14W14B	102	0.747	0.460	0.708	1.073	2.198	1.921	2.105	0.146
ST14W14C	103	0.740	0.474	0.701	1.020	2.198	1.929	2.071	0.142
ST14W14D	69	0.749	0.467	0.711	1.022	2.241	1.869	2.081	0.125
ST14W15A	103	0.770	0.492	0.728	1.100	2.198	1.934	2.076	0.144
ST14W15B	103	0.769	0.486	0.724	1.063	2.198	1.914	2.090	0.157
ST14W15C	103	0.752	0.479	0.717	1.025	2.198	1.916	2.066	0.152
ST14W15D	69	0.751	0.466	0.706	1.006	2.241	1.868	2.072	0.119
ST14W16A	104	0.773	0.488	0.727	1.066	2.198	1.902	2.064	0.142
ST14W16B	103	0.765	0.492	0.721	1.040	2.198	1.934	2.053	0.149
ST14W16C	100	0.776	0.509	0.741	1.072	2.198	2.013	2.103	0.159
ST14W16D				No Data Recorded					
Averages		0.725	0.462	0.687	0.973	2.194	1.922	2.060	0.152

(Continued)

(Sheet 2 of 4)

Table B14 (Continued)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	HL/3 (ft)	Hmax (ft)	Tpc (sec)	Tbar (sec)	T1/3 (sec)	Reflect. Coeff.
<u>Nearshore Wave Gage Averages</u>									
ST14W01	30	0.498	0.322	0.498	0.788	2.275	1.987	2.035	0.406
ST14W02	31	0.529	0.329	0.520	0.862	2.123	1.946	2.034	0.261
ST14W03A	28	0.528	0.350	0.536	0.844	2.069	2.025	2.089	0.222
ST14W03B	83	0.639	0.401	0.627	0.903	2.286	1.898	2.129	0.272
ST14W04A	137	0.639	0.392	0.626	0.934	2.167	1.889	2.150	0.264
ST14W04B	80	0.691	0.432	0.645	0.968	2.162	1.871	2.076	0.180
ST14W05A	81	0.666	0.418	0.649	0.943	2.286	1.938	2.128	0.270
ST14W05B	141	0.679	0.424	0.661	0.961	2.215	1.932	2.189	0.252
ST14W06A	109	0.655	0.390	0.617	0.946	2.283	1.872	2.135	0.251
ST14W06B	85	0.659	0.409	0.637	0.938	2.361	1.979	2.278	0.236
ST14W06C				No Data Recorded					
ST14W06D				No Data Recorded					
ST14W07A	78	0.635	0.387	0.612	0.972	2.344	1.892	2.156	0.209
ST14W07B	103	0.669	0.413	0.650	0.872	2.273	1.936	2.176	0.194
ST14W07C	102	0.686	0.415	0.643	0.997	2.326	1.948	2.201	0.210
ST14W07D	101	0.685	0.426	0.658	0.933	2.326	1.970	2.193	0.211
ST14W08A	64	0.719	0.439	0.681	1.010	2.144	1.960	2.182	0.226
ST14W08B	87	0.699	0.433	0.676	0.987	2.303	1.964	2.192	0.213
ST14W08C	101	0.706	0.439	0.680	1.009	2.326	1.960	2.189	0.210
ST14W08D	87	0.710	0.444	0.687	0.969	2.303	1.981	2.232	0.202
ST14W09A	99	0.702	0.445	0.683	0.963	2.326	1.998	2.230	0.212
ST14W09B	101	0.709	0.442	0.686	0.978	2.326	1.959	2.250	0.211
ST14W09C	81	0.702	0.451	0.698	0.994	2.357	2.011	2.236	0.217
ST14W09D	97	0.723	0.463	0.706	1.010	2.326	2.009	2.227	0.217
ST14W09E				No Data Recorded					
ST14W10A	101	0.643	0.401	0.619	0.893	2.326	1.959	2.202	0.225
ST14W10B	101	0.659	0.420	0.651	0.922	2.326	1.971	2.233	0.225
ST14W10C	101	0.666	0.419	0.650	0.889	2.198	1.956	2.188	0.222

(Continued)

(Sheet 3 of 4)

Table B14 (Concluded)

Filename	Total Waves	Hmo (ft)	Hbar (ft)	Hl/3 (ft)	Hmax (ft)	TpC (sec)	Tbar (sec)	Tl/3 (sec)	Reflect. Coeff.
ST14WL10D	101	0.662	0.422	0.652	0.920	2.326	1.977	2.224	0.226
ST14WL10E				No Data Recorded					
ST14WL11A	100	0.600	0.443	0.683	0.950	2.326	2.005	2.256	0.212
ST14WL11B	100	0.600	0.437	0.668	0.923	2.326	2.023	2.164	0.213
ST14WL11C	98	0.600	0.442	0.670	0.933	2.326	2.032	2.217	0.208
ST14WL11D	63	0.652	0.421	0.672	0.910	2.241	2.035	2.211	0.229
ST14WL11E				No Data Recorded					
ST14WL12A	99	0.683	0.439	0.671	0.925	2.326	2.007	2.230	0.215
ST14WL12B	100	0.685	0.435	0.673	0.940	2.326	1.971	2.214	0.213
ST14WL12C	98	0.682	0.444	0.677	0.946	2.326	2.022	2.246	0.205
ST14WL12D	61	0.676	0.441	0.678	0.909	2.241	2.078	2.233	0.207
ST14WL12E				No Data Recorded					
ST14WL13A	100	0.665	0.419	0.650	0.939	2.326	1.972	2.186	0.215
ST14WL13B	101	0.671	0.426	0.659	0.919	2.198	1.950	2.167	0.209
ST14WL13C	100	0.669	0.425	0.653	0.944	2.198	1.965	2.171	0.199
ST14WL13D	100	0.684	0.434	0.677	0.954	2.198	1.986	2.178	0.215
ST14WL13E	102	0.691	0.434	0.679	0.930	2.326	1.953	2.198	0.214
ST14WL13F	64	0.651	0.408	0.645	0.925	2.241	1.972	2.232	0.217
ST14WL14A	98	0.681	0.443	0.672	0.945	2.326	2.033	2.220	0.204
ST14WL14B	100	0.695	0.438	0.683	0.924	2.198	1.986	2.229	0.207
ST14WL14C	100	0.689	0.436	0.680	0.954	2.198	1.965	2.166	0.198
ST14WL14D	64	0.666	0.421	0.660	0.943	2.241	2.006	2.198	0.207
ST14WL15A	100	0.709	0.450	0.703	0.971	2.326	1.994	2.211	0.207
ST14WL15B	101	0.713	0.449	0.702	0.969	2.326	1.958	2.221	0.211
ST14WL15C	101	0.692	0.438	0.685	0.912	2.198	1.965	2.171	0.201
ST14WL15D	64	0.666	0.415	0.655	0.961	2.241	1.984	2.196	0.193
ST14WL16A	98	0.709	0.456	0.701	0.945	2.326	2.013	2.234	0.206
ST14WL16B	96	0.706	0.468	0.699	0.980	2.326	2.064	2.251	0.208
ST14WL16C	101	0.721	0.458	0.711	0.956	2.198	1.969	2.188	0.207
ST14WL16D				No Data Recorded					
Averages		0.607	0.416	0.645	0.921	2.229	1.936	2.149	0.217

(Sheet 4 of 4)



## APPENDIX C: TABLES OF EXPERIMENT PROFILES

1. This appendix contains profile range and elevation coordinates (model units) for all profiles recorded during the experimental test series. Elevation measurements are relative to still-water level in the wave tank. Profiles have been named using the following convention. The first three characters of the name denote the test number. The fourth character is typically "P" (meaning center line), but can be "G" (glass sidewall) or "C" (concrete sidewall). The rest of the name (two to four characters) represents the number of waves from the start of the test. For example, profile T04P1450 is a center-line profile from test T04 after 1,450 waves.

<u>Test</u>	<u>Description of Test</u>	<u>Table Number</u>
T01	Reproduction of prototype experiment using 10-m horizontal width berm	Table C1
T02	Repeat of T01 to demonstrate repeatability	Table C2
T03	Reproduction of prototype experiment using 11-m horizontal width berm (same as prototype)	Table C3
T04	Repeat of T03 with wave height increased by 10 percent to examine impact of height variations	Table C4
T05	Repeat of T03 using absorbing wave paddle	Table C5
T06	Repeat of T03 starting with the prototype profile at 40 waves molded in the flume	Table C6
T07	Repeat of T03 with wave period decreased 10 percent to examine impact of period variations	Table C7
T08	Repeat of T03 using irregular waves having $H_{1/3}$ equal to 110 percent of monochromatic wave height	Table C8
T09	Repeat of T03 using irregular waves having $H_{1/3}$ equal to the monochromatic wave height	Table C9
T10	Repeat of T03 using regular waves with a vertical seawall at the intersection of the revetment and still-water level	Table C10
T11	Repeat of T10 using irregular waves with $H_{1/3}$ equal to the monochromatic wave height	Table C11
T12	Undocumented repeat test of T08	Table C12
T13	Aborted irregular wave test	Table C13
T14	Reproduction of prototype irregular wave test	Table C14

Table C1

Profile Survey Data, Test T01

Profile T01START		Profile T01P40		Profile T01P80		Profile T01P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-2.00	0.80	-2.00	0.80	-2.00	0.80	-2.00	0.80
-1.00	0.79	-1.00	0.79	-1.00	0.79	-1.20	0.76
0.00	0.62	0.00	0.64	0.00	0.62	-1.00	0.12
0.30	0.01	0.30	0.58	0.30	0.01	-0.40	0.01
1.00	-0.14	0.60	0.50	1.00	-0.14	0.00	-0.04
2.00	-0.30	0.90	0.26	2.00	-0.30	0.90	-0.20
3.00	-0.40	1.15	-0.04	3.00	-0.40	1.00	-0.24
3.70	-0.43	1.55	-0.11	3.70	-0.43	2.00	-0.32
4.00	-0.47	2.00	-0.20	4.00	-0.47	3.00	-0.40
5.00	-0.62	3.00	-0.32	5.00	-0.62	3.50	-0.45
5.50	-0.60	4.00	-0.46	5.50	-0.60	4.00	-0.51
6.00	-0.63	5.00	-0.56	6.00	-0.63	4.50	-0.64
7.00	-0.75	6.00	-0.64	7.00	-0.75	5.00	-0.77
8.00	-0.91	7.00	-0.82	8.00	-0.91	5.30	-0.79
9.00	-1.12	7.50	-0.97	9.00	-1.12	6.00	-0.72
9.50	-1.21	8.00	-1.02	9.50	-1.21	7.00	-0.67
10.00	-1.42	9.00	-1.35	10.00	-1.42	8.00	-0.78
11.00	-1.69	10.00	-1.59	11.00	-1.69	9.00	-1.02
12.00	-1.86	11.00	-1.78	12.00	-1.86	10.00	-1.21
13.00	-1.97	12.00	-1.93	13.00	-1.97	11.00	-1.54
14.00	-2.00	13.00	-2.01	14.00	-2.00	12.00	-1.78
15.00	-2.09	14.00	-2.04	15.00	-2.09	13.00	-1.93
16.00	-2.12	15.00	-2.09	16.00	-2.12	14.00	-1.99
17.00	-2.17	16.00	-2.13	17.00	-2.17	15.00	-2.05
18.00	-2.19	17.00	-2.17	18.00	-2.19	16.00	-2.10
		18.00	-2.18			17.00	-2.14
						18.00	-2.17

(Continued)

(Sheet 1 of 3)

Table C1 (Continued)

Profile T01P370		Profile T01P750		Profile T01P1450		Profile T01P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.00	0.81	-3.50	0.80	-3.50	0.80	-3.70	0.81
-2.00	0.73	-3.00	0.80	-3.40	0.59	-3.59	0.64
-1.80	0.22	-2.80	0.77	-2.00	0.24	-2.00	0.24
-1.00	0.02	-2.60	0.40	-1.00	-0.01	-1.00	-0.01
0.00	-0.17	-2.00	0.24	0.00	-0.26	0.00	-0.26
1.00	-0.27	-1.00	-0.01	0.60	-0.40	0.80	-0.47
2.00	-0.33	-0.30	-0.19	1.00	-0.43	1.00	-0.48
3.00	-0.48	0.00	-0.25	1.50	-0.43	1.50	-0.42
3.50	-0.49	1.00	-0.31	2.00	-0.43	2.00	-0.42
4.00	-0.49	2.00	-0.37	2.50	-0.45	2.50	-0.51
5.00	-0.63	2.30	-0.38	3.00	-0.58	3.00	-0.55
5.50	-0.84	3.00	-0.50	3.50	-0.57	3.25	-0.53
6.00	-0.94	4.00	-0.55	4.00	-0.50	3.50	-0.49
6.50	-0.87	5.00	-0.60	4.50	-0.51	4.00	-0.45
7.00	-0.67	5.50	-0.72	5.00	-0.58	4.50	-0.52
7.50	-0.62	6.00	-0.90	5.50	-0.71	5.00	-0.64
8.00	-0.66	6.50	-0.94	6.00	-0.89	5.50	-0.83
9.00	-0.77	7.00	-0.83	6.50	-0.94	6.00	-0.92
10.00	-0.95	7.50	-0.68	7.00	-0.86	6.50	-0.88
11.00	-1.32	8.00	-0.64	7.50	-0.68	7.00	-0.73
12.00	-1.70	9.00	-0.72	8.00	-0.63	7.50	-0.61
13.00	-1.90	10.00	-0.85	8.50	-0.64	8.00	-0.58
14.00	-1.96	11.00	-1.05	9.00	-0.69	8.50	-0.63
15.00	-2.01	11.50	-1.26	10.00	-0.81	9.00	-0.69
16.00	-2.09	12.00	-1.53	11.00	-0.98	10.00	-0.83
17.00	-2.14	13.00	-1.87	12.00	-1.28	11.00	-1.00
18.00	-2.15	14.00	-1.92	13.00	-1.80	12.00	-1.31
		15.00	-2.00	14.00	-1.92	13.00	-1.77
		16.00	-2.06	15.00	-1.94	14.00	-1.91
		17.00	-2.10	16.00	-2.03	15.00	-1.95
		18.00	-2.13	17.00	-2.08	16.00	-2.03
				18.00	-2.11	17.00	-2.07
						18.00	-2.11

(Continued)

(Sheet 2 of 3)

Table C1 (Concluded)

Profile T01G1650		Profile T01C1650		Profile T01P1850		Profile T01P2050	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
0.00	-0.26	0.00	-0.26	-3.70	0.82	-3.80	0.82
0.50	-0.39	0.50	-0.39	-3.59	0.63	-3.73	0.67
1.00	-0.48	1.00	-0.49	-2.00	0.24	-1.00	-0.01
1.50	-0.47	1.50	-0.60	-1.00	0.00	0.00	-0.26
2.00	-0.49	2.00	-0.61	0.00	-0.27	0.80	-0.46
2.50	-0.55	2.50	-0.63	0.90	-0.47	1.00	-0.48
3.00	-0.52	3.00	-0.63	1.00	-0.48	1.50	-0.43
3.50	-0.46	3.50	-0.68	1.50	-0.43	2.00	-0.43
4.00	-0.48	4.00	-0.78	2.00	-0.46	2.50	-0.50
4.50	-0.54	4.50	-0.86	2.50	-0.52	3.00	-0.53
5.00	-0.68	5.00	-0.84	3.00	-0.54	3.50	-0.47
5.50	-0.84	5.50	-0.83	3.50	-0.47	4.00	-0.44
6.00	-0.89	6.00	-0.96	4.00	-0.44	4.50	-0.52
6.50	-0.76	6.50	-1.18	4.50	-0.51	5.00	-0.66
7.00	-0.64	7.00	-1.32	5.00	-0.64	5.50	-0.82
7.50	-0.61	7.50	-1.32	5.50	-0.82	6.00	-0.91
8.00	-0.62	8.00	-1.11	6.00	-0.92	6.50	-0.86
8.50	-0.66	8.50	-0.84	6.50	-0.87	7.00	-0.74
9.00	-0.74	9.00	-0.74	7.00	-0.71	7.50	-0.63
10.00	-0.89	9.50	-0.77	7.50	-0.62	8.00	-0.59
11.00	-1.10	10.00	-0.81	8.00	-0.59	8.50	-0.63
12.00	-1.40	10.50	-0.84	8.50	-0.62	9.00	-0.68
13.00	-1.74	11.00	-0.89	9.00	-0.69	10.00	-0.82
14.00	-1.90	12.00	-1.07	9.50	-0.74	11.00	-1.00
15.00	-1.94	13.00	-1.67	10.00	-0.83	12.00	-1.32
16.00	-2.04	14.00	-1.92	11.00	-1.00	13.00	-1.74
17.00	-2.00	15.00	-1.97	12.00	-1.32	14.00	-1.88
18.00	-2.00	16.00	-2.02	13.00	-1.75	15.00	-1.97
		17.00	-1.99	14.00	-1.89	16.00	-2.01
		18.00	-2.12	15.00	-1.96	17.00	-2.07
				16.00	-2.03	18.00	-2.12
				17.00	-2.07		
				18.00	-2.11		

(Sheet 3 of 3)

Table C2

Profile Survey Data, Test T02

Profile T02START		Profile T02P40		Profile T02P80		Profile T02P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.90	-3.00	0.91	-3.00	0.91	-3.00	0.91
-4.00	0.90	-2.00	0.92	-2.00	0.92	-2.00	0.92
-3.00	0.90	-1.00	0.90	-1.00	0.90	-1.30	0.90
-2.00	0.91	-0.60	0.87	-0.60	0.83	-0.90	0.10
-1.00	0.90	0.00	0.63	-0.30	0.15	-0.50	0.02
0.00	0.72	0.30	0.02	0.00	0.08	0.00	-0.04
1.00	0.51	0.80	-0.06	0.50	-0.04	0.50	-0.10
2.00	0.28	1.00	-0.10	1.00	-0.13	1.00	-0.17
3.00	0.03	2.00	-0.23	2.00	-0.29	2.00	-0.28
4.00	-0.13	3.00	-0.35	3.00	-0.40	2.50	-0.32
5.00	-0.50	4.00	-0.45	3.50	-0.41	3.00	-0.39
6.00	-0.72	5.00	-0.54	4.00	-0.48	3.50	-0.44
7.00	-0.93	5.50	-0.56	4.80	-0.67	4.00	-0.46
7.87	-1.15	6.00	-0.61	5.00	-0.65	4.50	-0.57
8.00	-1.18	6.50	-0.68	5.50	-0.59	5.00	-0.76
9.00	-1.29	7.00	-0.78	6.00	-0.59	5.50	-0.80
10.00	-1.64	7.50	-0.90	6.50	-0.64	6.00	-0.70
11.00	-1.85	8.00	-1.04	7.00	-0.72	6.50	-0.62
12.00	-2.03	8.50	-1.17	7.50	-0.80	7.00	-0.63
13.00	-2.18	9.00	-1.27	8.00	-0.90	7.50	-0.67
		10.00	-1.46	8.50	-0.99	8.00	-0.74
		11.00	-1.64	9.00	-1.14	8.50	-0.82
		12.00	-1.83	10.00	-1.40	9.00	-0.94
		13.00	-2.01	11.00	-1.61	10.00	-1.26
		14.00	-2.08	12.00	-1.80	10.50	-1.39
		15.00	-2.13	13.00	-2.01	11.00	-1.53
		16.00	-2.16	14.00	-2.08	12.00	-1.76
		17.00	-2.18	15.00	-2.13	13.00	-1.97
		18.00	-2.19	16.00	-2.15	14.00	-2.08
				17.00	-2.18	15.00	-2.12
				18.00	-2.19	16.00	-2.14
						17.00	-2.17
						18.00	-2.17

(Continued)

(Sheet 1 of 3)

Table C2 (Continued)

Profile	T02P370	Profile	T02P750	Profile	T02P1450	Profile	T02P1650
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.00	0.91	-3.50	0.89	-3.60	0.86	0.00	-0.27
-2.50	0.90	-2.90	0.90	-3.40	0.58	0.50	-0.37
-2.30	0.30	-2.80	0.45	-3.00	0.50	1.00	-0.43
-1.50	0.15	-2.00	0.23	-2.00	0.25	1.50	-0.44
-1.00	0.05	-1.00	-0.02	-1.00	-0.01	2.00	-0.45
-0.50	-0.05	0.00	-0.23	0.00	-0.25	2.50	-0.42
0.00	-0.15	0.50	-0.26	0.50	-0.36	3.00	-0.53
0.50	-0.20	1.00	-0.28	1.00	-0.41	3.50	-0.59
1.00	-0.23	1.50	-0.30	1.50	-0.42	4.00	-0.56
1.50	-0.27	2.00	-0.32	2.00	-0.40	4.50	-0.52
2.00	-0.30	2.50	-0.36	2.50	-0.42	5.00	-0.54
2.50	-0.36	3.00	-0.45	3.00	-0.47	5.50	-0.58
3.00	-0.46	3.50	-0.54	3.50	-0.57	6.00	-0.76
3.50	-0.47	4.00	-0.58	4.00	-0.57	6.50	-0.92
4.00	-0.50	4.50	-0.57	4.50	-0.53	7.00	-0.89
4.50	-0.53	5.00	-0.58	5.00	-0.54	7.50	-0.74
5.00	-0.57	5.50	-0.66	5.50	-0.58	8.00	-0.59
5.50	-0.77	6.00	-0.87	6.00	-0.75	8.50	-0.60
6.00	-0.91	6.50	-0.93	6.50	-0.91	9.00	-0.67
6.50	-0.86	7.00	-0.84	7.00	-0.88	9.50	-0.74
7.00	-0.69	7.50	-0.67	7.50	-0.72	10.00	-0.80
7.50	-0.62	8.00	-0.62	8.00	-0.61	11.00	-0.93
8.00	-0.65	8.50	-0.64	8.50	-0.61	11.50	-1.04
8.50	-0.71	9.00	-0.72	9.00	-0.67	12.00	-1.27
9.00	-0.78	10.00	-0.85	10.00	-0.80	12.50	-1.53
10.00	-0.94	10.50	-0.91	11.00	-0.96	13.00	-1.79
11.00	-1.29	11.00	-1.01	12.00	-1.29	14.00	-1.97
12.00	-1.68	12.00	-1.45	13.00	-1.84	15.00	-2.01
13.00	-1.93	13.00	-1.88	14.00	-1.96	16.00	-2.06
14.00	-2.03	14.00	-1.97	15.00	-2.00	17.00	-2.10
15.00	-2.08	15.00	-2.04	16.00	-2.05	18.00	-2.13
16.00	-2.12	16.00	-2.09	17.00	-2.09		
17.00	-2.14	17.00	-2.12	18.00	-2.13		
18.00	-2.15	18.00	-2.14				

(Continued)

(Sheet 2 of 3)

Table C2 (Concluded)

Profile T02G1650		Profile T02C1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
0.00	-0.26	0.00	-0.28
1.00	-0.49	0.50	-0.40
1.50	-0.45	1.00	-0.53
2.00	-0.43	1.50	-0.57
2.50	-0.48	2.00	-0.56
3.00	-0.59	2.50	-0.54
3.50	-0.62	3.00	-0.57
4.00	-0.59	3.50	-0.65
4.50	-0.58	4.00	-0.76
5.00	-0.60	4.50	-0.79
5.50	-0.66	5.00	-0.76
6.00	-0.85	5.50	-0.73
6.50	-0.94	6.00	-0.86
7.00	-0.82	6.50	-1.13
7.50	-0.68	7.00	-1.24
8.00	-0.62	7.50	-1.22
8.50	-0.63	8.00	-1.07
9.00	-0.69	8.50	-0.83
9.50	-0.74	9.00	-0.73
10.00	-0.83	9.50	-0.76
11.00	-0.99	10.00	-0.81
12.00	-1.33	10.50	-0.87
13.00	-1.79	11.00	-0.92
14.00	-1.95	11.50	-0.99
15.00	-1.99	12.00	-1.09
16.00	-2.03	12.50	-1.40
17.00	-2.07	13.00	-1.69
18.00	-2.11	14.00	-1.97
		15.00	-2.02
		16.00	-2.04
		17.00	-2.09
		18.00	-2.13

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Table C3

Profile Survey Data, Test T03

Profile T03START		Profile T03P40		Profile T03P80		Profile T03P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.94	-2.00	0.93	-2.00	0.94	-2.00	0.93
-4.00	0.94	-1.00	0.92	-1.00	0.91	-1.20	0.88
-3.00	0.94	0.00	0.85	-0.50	0.91	-1.00	0.16
-2.00	0.94	0.40	0.73	0.00	0.12	0.00	0.02
-1.00	0.92	0.70	0.09	0.50	0.00	0.50	-0.08
0.00	0.88	1.00	0.02	1.00	-0.09	1.00	-0.17
1.00	0.70	1.50	-0.06	1.50	-0.19	1.50	-0.23
2.00	0.44	2.00	-0.14	2.00	-0.24	2.00	-0.26
3.00	0.16	2.50	-0.22	2.50	-0.29	2.50	-0.32
4.00	-0.11	3.00	-0.29	3.00	-0.36	3.00	-0.37
5.00	-0.39	3.50	-0.37	3.50	-0.37	3.50	-0.42
6.00	-0.64	4.00	-0.44	4.00	-0.40	4.00	-0.45
7.00	-0.86	4.50	-0.49	4.50	-0.51	4.50	-0.48
7.87	-1.05	5.00	-0.52	5.00	-0.67	5.00	-0.60
8.00	-1.08	5.50	-0.54	5.50	-0.74	5.50	-0.76
9.00	-1.30	6.00	-0.59	6.00	-0.64	6.00	-0.83
10.00	-1.54	6.50	-0.65	6.50	-0.61	6.50	-0.75
11.00	-1.78	7.00	-0.72	7.00	-0.62	7.00	-0.66
12.00	-1.99	7.50	-0.80	7.50	-0.67	7.50	-0.66
13.00	-2.14	8.00	-0.93	8.00	-0.75	8.00	-0.68
14.00	-2.18	9.00	-1.22	8.50	-0.83	8.50	-0.75
		10.00	-1.43	9.00	-0.92	9.00	-0.82
		11.00	-1.63	10.00	-1.26	10.00	-1.01
		12.00	-1.81	11.00	-1.54	11.00	-1.35
		13.00	-2.00	12.00	-1.76	12.00	-1.65
		14.00	-2.07	13.00	-1.96	13.00	-1.89
		15.00	-2.11	14.00	-2.05	14.00	-2.00
		16.00	-2.14	15.00	-2.09	15.00	-2.06
		17.00	-2.17	16.00	-2.12	16.00	-2.09
		18.00	-2.17	17.00	-2.16	17.00	-2.14
				18.00	-2.16	18.00	-2.16

(Continued)

(Sheet 1 of 3)

Table C3 (Continued)

Profile T03P370		Profile T03P750		Profile T03P1450		Profile T03P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.00	0.94	-3.00	0.94	-3.50	0.95	-3.30	0.93
-2.00	0.92	-2.70	0.92	-3.20	0.91	-3.10	0.49
-1.80	0.30	-2.50	0.35	-2.90	0.46	-2.00	0.25
-1.50	0.22	-2.00	0.24	-2.00	0.24	-1.00	0.00
-1.00	0.12	-1.50	0.12	-1.00	-0.01	0.00	-0.26
0.00	-0.09	-1.00	0.04	-0.50	-0.13	0.50	-0.29
0.50	-0.17	-0.50	-0.07	0.00	-0.23	1.00	-0.35
1.00	-0.21	0.00	-0.16	0.50	-0.25	1.50	-0.34
1.50	-0.25	0.50	-0.20	1.00	-0.32	2.00	-0.34
2.00	-0.29	1.00	-0.24	1.50	-0.33	2.50	-0.36
2.50	-0.36	1.50	-0.25	2.00	-0.32	3.00	-0.39
3.00	-0.40	2.00	-0.29	2.50	-0.35	3.50	-0.43
3.50	-0.44	2.50	-0.32	3.00	-0.38	4.00	-0.50
4.00	-0.46	3.00	-0.36	3.50	-0.43	4.50	-0.52
4.50	-0.49	3.50	-0.43	4.00	-0.50	5.00	-0.51
5.00	-0.53	4.00	-0.49	4.50	-0.52	5.50	-0.52
5.50	-0.65	4.50	-0.53	5.00	-0.51	6.00	-0.55
6.00	-0.85	5.00	-0.50	5.50	-0.51	6.50	-0.77
6.50	-0.88	5.50	-0.56	6.00	-0.61	7.00	-0.85
7.00	-0.78	6.00	-0.74	6.50	-0.76	7.50	-0.81
7.50	-0.62	6.50	-0.89	7.00	-0.84	8.00	-0.69
8.00	-0.61	7.00	-0.83	7.50	-0.77	8.50	-0.60
8.50	-0.65	7.50	-0.67	8.00	-0.64	9.00	-0.62
9.00	-0.71	8.00	-0.60	8.50	-0.59	9.50	-0.67
10.00	-0.86	8.50	-0.62	9.00	-0.62	10.00	-0.73
11.00	-1.10	9.00	-0.66	9.50	-0.68	10.50	-0.80
12.00	-1.54	9.50	-0.72	10.00	-0.75	11.00	-0.88
13.00	-1.86	10.00	-0.79	10.50	-0.81	12.00	-1.14
14.00	-1.97	11.00	-0.94	11.00	-0.89	13.00	-1.63
15.00	-2.04	12.00	-1.38	12.00	-1.18	14.00	-1.92
16.00	-2.07	13.00	-1.83	13.00	-1.68	15.00	-1.95
17.00	-2.12	14.00	-1.93	14.00	-1.93	16.00	-2.01
18.00	-2.15	15.00	-1.98	15.00	-1.95	17.00	-2.05
		16.00	-2.04	16.00	-2.03	18.00	-2.10
		17.00	-2.09	17.00	-2.05		
		18.00	-2.13	18.00	-2.10		

(Continued)

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Table C3 (Concluded)

Profile T03G1650		Profile T03C1650		Profile T03P1850	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
0.00	-0.24	0.00	-0.26	0.00	-0.27
0.50	-0.33	0.50	-0.36	0.50	-0.30
1.00	-0.37	1.00	-0.41	1.00	-0.31
1.50	-0.39	1.50	-0.41	1.50	-0.36
2.00	-0.38	2.00	-0.42	2.00	-0.35
2.50	-0.39	2.50	-0.42	2.50	-0.35
3.00	-0.43	3.00	-0.49	3.00	-0.38
3.50	-0.49	3.50	-0.52	3.50	-0.42
4.00	-0.58	4.00	-0.63	4.00	-0.49
4.50	-0.65	4.50	-0.71	4.50	-0.50
5.00	-0.65	5.00	-0.72	5.00	-0.48
5.50	-0.61	5.50	-0.70	5.50	-0.49
6.00	-0.65	6.00	-0.71	6.00	-0.57
6.50	-0.70	6.50	-0.89	6.50	-0.78
7.00	-0.90	7.00	-1.09	7.00	-0.87
7.50	-0.82	7.50	-1.16	7.50	-0.81
8.00	-0.68	8.00	-1.08	8.00	-0.67
8.50	-0.62	8.50	-0.89	8.50	-0.60
9.00	-0.63	9.00	-0.73	9.00	-0.62
9.50	-0.68	9.50	-0.73	9.50	-0.65
10.00	-0.74	10.00	-0.76	10.00	-0.73
11.00	-0.89	11.00	-0.88	11.00	-0.88
12.00	-1.21	12.00	-1.02	12.00	-1.11
13.00	-1.66	13.00	-1.54	13.00	-1.56
14.00	-1.93	14.00	-1.88	14.00	-1.92
15.00	-1.97	15.00	-1.89	15.00	-1.94
16.00	-2.03	16.00	-1.96	16.00	-1.97
17.00	-2.08	17.00	-2.03	17.00	-2.05
18.00	-2.12	18.00	-2.07	18.00	-2.09

(Sheet 3 of 3)

Table C4

Profile Survey Data, Test T04

Profile T04START		Profile T04P40		Profile T04P80		Profile T04P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.91	-3.00	0.92	-3.00	0.92	-3.00	0.92
-4.00	0.91	-2.00	0.92	-2.00	0.92	-2.00	0.91
-3.00	0.91	-1.00	0.90	-0.90	0.89	-1.70	0.90
-2.00	0.90	-0.50	0.87	-0.50	0.12	-1.40	0.20
-1.00	0.88	0.00	0.66	0.00	0.03	-1.00	0.12
0.00	0.83	0.30	0.08	0.50	-0.05	0.00	-0.07
1.00	0.65	1.00	-0.09	1.00	-0.15	0.50	-0.14
2.00	0.39	2.00	-0.24	1.50	-0.22	1.00	-0.20
3.00	0.08	3.00	-0.35	2.00	-0.29	1.50	-0.25
4.00	-0.18	4.00	-0.50	2.50	-0.34	2.00	-0.28
5.00	-0.44	4.50	-0.59	3.00	-0.37	2.50	-0.33
6.00	-0.66	5.00	-0.60	3.50	-0.40	3.00	-0.39
7.00	-0.88	5.50	-0.61	4.00	-0.48	3.50	-0.44
7.87	-1.09	6.00	-0.61	4.50	-0.63	4.00	-0.47
8.00	-1.12	6.50	-0.64	5.00	-0.76	4.50	-0.53
9.00	-1.32	7.00	-0.72	5.50	-0.72	5.00	-0.66
10.00	-1.56	7.50	-0.82	6.00	-0.64	5.50	-0.82
11.00	-1.74	8.00	-0.93	6.50	-0.62	6.00	-0.89
12.00	-1.98	8.50	-1.04	7.00	-0.65	6.50	-0.79
13.00	-2.17	9.00	-1.14	7.50	-0.70	7.00	-0.70
14.00	-2.20	9.50	-1.26	8.00	-0.76	7.50	-0.67
		10.00	-1.34	8.50	-0.83	8.00	-0.67
		11.00	-1.53	9.00	-0.93	8.50	-0.72
		12.00	-1.73	9.50	-1.04	9.00	-0.79
		13.00	-1.84	10.00	-1.21	9.50	-0.90
		14.00	-1.92	11.00	-1.45	10.00	-1.01
		15.00	-2.01	12.00	-1.67	11.00	-1.26
		16.00	-2.09	13.00	-1.80	12.00	-1.55
		17.00	-2.14	14.00	-1.90	13.00	-1.74
		18.00	-2.15	15.00	-2.00	14.00	-1.87
				16.00	-2.08	15.00	-1.97
				17.00	-2.13	16.00	-2.06
				18.00	-2.15	17.00	-2.11
						18.00	-2.13

(Continued)

(Sheet 1 of 3)

Table C4 (Continued)

Profile T04P370		Profile T04P750		Profile T04P1450		Profile T04P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.00	0.93	-3.50	0.91	-3.70	0.87	-3.80	0.90
-2.60	0.90	-3.10	0.86	-3.60	0.62	-3.60	0.64
-2.40	0.34	-2.90	0.46	-3.00	0.50	-2.00	0.24
-2.00	0.25	0.00	-0.25	-2.00	0.24	-1.00	-0.01
-1.00	0.05	0.50	-0.28	-1.00	-0.01	0.00	-0.26
-0.50	-0.07	1.00	-0.31	0.00	-0.25	1.00	-0.41
0.00	-0.15	1.50	-0.31	0.50	-0.39	1.50	-0.44
0.50	-0.20	2.00	-0.35	1.00	-0.44	2.00	-0.43
1.00	-0.23	2.50	-0.37	1.50	-0.43	2.50	-0.42
1.50	-0.27	3.00	-0.46	2.00	-0.41	3.00	-0.46
2.00	-0.30	3.50	-0.55	2.50	-0.40	3.50	-0.56
2.50	-0.35	4.00	-0.57	3.00	-0.45	4.00	-0.61
3.00	-0.44	4.50	-0.56	3.50	-0.56	4.50	-0.57
3.50	-0.50	5.00	-0.56	4.00	-0.60	5.00	-0.54
4.00	-0.49	5.50	-0.59	4.50	-0.58	5.50	-0.56
4.50	-0.52	6.00	-0.82	5.00	-0.56	6.00	-0.64
5.00	-0.58	6.50	-0.98	5.50	-0.57	6.50	-0.88
5.50	-0.76	7.00	-1.06	6.00	-0.63	7.00	-1.06
6.00	-0.94	7.50	-0.99	6.50	-0.84	7.50	-1.07
6.50	-1.00	8.00	-0.76	7.00	-1.00	8.00	-0.94
7.00	-0.93	8.50	-0.63	7.50	-1.04	8.50	-0.76
7.50	-0.75	9.00	-0.64	8.00	-0.94	9.00	-0.63
8.00	-0.64	9.50	-0.70	8.50	-0.77	9.50	-0.65
8.50	-0.65	10.00	-0.77	9.00	-0.67	10.00	-0.70
9.00	-0.69	11.00	-0.90	9.50	-0.66	10.50	-0.76
9.50	-0.77	12.00	-1.09	10.00	-0.71	11.00	-0.83
10.00	-0.83	13.00	-1.54	10.50	-0.76	11.50	-0.89
11.00	-1.02	14.00	-1.84	11.00	-0.83	12.00	-0.91
12.00	-1.32	15.00	-1.91	11.50	-0.90	13.00	-1.19
13.00	-1.66	16.00	-1.99	12.00	-0.97	14.00	-1.75
14.00	-1.85	17.00	-2.05	13.00	-1.25	15.00	-1.90
15.00	-1.95	18.00	-2.09	13.50	-1.50	16.00	-1.94
16.00	-2.02			14.00	-1.76	17.00	-2.00
17.00	-2.08			15.00	-1.89	18.00	-2.03
18.00	-2.10			16.00	-1.94		
				17.00	-2.00		
				18.00	-2.08		

(Continued)

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Table C4 (Concluded)

Profile T04G1650		Profile T04C1650		Profile T04P1850	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
0.00	-0.26	0.00	-0.26	-3.90	0.91
1.00	-0.50	1.00	-0.51	-3.80	0.69
1.50	-0.51	1.50	-0.61	0.00	-0.26
2.00	-0.49	2.00	-0.61	1.00	-0.45
2.50	-0.52	2.50	-0.59	1.50	-0.46
3.00	-0.59	3.00	-0.62	2.00	-0.46
3.50	-0.68	3.50	-0.70	2.50	-0.43
4.00	-0.69	4.00	-0.80	3.00	-0.50
4.50	-0.63	4.50	-0.88	3.50	-0.56
5.00	-0.62	5.00	-0.88	4.00	-0.57
5.50	-0.66	5.50	-0.86	4.50	-0.52
6.00	-0.85	6.00	-0.87	5.00	-0.52
6.50	-1.02	6.50	-1.03	5.50	-0.56
7.00	-1.06	7.00	-1.26	6.00	-0.67
7.50	-0.93	7.50	-1.42	6.50	-0.89
8.00	-0.78	8.00	-1.43	7.00	-1.00
8.50	-0.70	8.50	-1.29	7.50	-1.01
9.00	-0.69	9.00	-1.00	8.00	-0.88
9.50	-0.71	9.50	-0.81	8.50	-0.73
10.00	-0.82	10.00	-0.80	9.00	-0.65
10.50	-0.82	10.50	-0.83	9.50	-0.66
11.00	-0.92	11.00	-0.88	10.00	-0.71
11.50	-0.97	11.50	-0.93	11.00	-0.82
12.00	-1.04	12.00	-0.99	12.00	-0.95
13.00	-1.35	13.00	-1.19	13.00	-1.16
14.00	-1.76	14.00	-1.75	13.50	-1.36
15.00	-1.91	15.00	-1.93	14.00	-1.67
16.00	-1.99	16.00	-1.99	15.00	-1.90
17.00	-2.02	17.00	-2.04	16.00	-1.92
18.00	-2.09	18.00	-2.10	17.00	-1.98
				18.00	-2.06

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Table C5

Profile Survey Data, Test T05

Profile T05START		Profile T05P40		Profile T05P80		Profile T05P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.97	-3.00	0.96	-3.00	0.95	-3.00	0.96
-4.00	0.97	-2.00	0.91	-1.75	0.88	-2.60	0.94
-3.00	0.96	-1.00	0.81	-1.55	0.13	-2.40	0.34
-2.00	0.91	-0.80	0.82	0.00	-0.16	-1.50	0.11
-1.00	0.83	-0.70	0.08	0.50	-0.23	0.00	-0.19
0.00	0.77	0.00	-0.06	1.00	-0.31	0.50	-0.23
1.00	0.69	0.50	-0.16	1.50	-0.37	1.00	-0.28
2.00	0.45	1.00	-0.22	2.00	-0.40	1.50	-0.32
3.00	0.21	1.50	-0.30	2.50	-0.42	2.00	-0.38
4.00	-0.05	2.00	-0.38	3.00	-0.47	2.50	-0.41
5.00	-0.39	2.50	-0.51	3.50	-0.57	3.00	-0.46
6.00	-0.62	3.00	-0.61	4.00	-0.67	3.50	-0.61
7.00	-0.77	3.50	-0.63	4.50	-0.69	4.00	-0.79
7.87	-1.10	4.00	-0.62	5.00	-0.62	4.50	-0.79
8.00	-1.15	4.50	-0.62	5.50	-0.60	5.00	-0.68
9.00	-1.40	5.00	-0.64	6.00	-0.62	5.50	-0.61
10.00	-1.65	5.50	-0.66	6.50	-0.66	6.00	-0.61
11.00	-1.87	6.00	-0.67	7.00	-0.72	6.50	-0.63
12.00	-2.02	6.50	-0.73	7.50	-0.80	7.00	-0.66
13.00	-2.12	7.00	-0.80	8.00	-0.91	7.50	-0.72
14.00	-2.20	7.50	-0.90	8.50	-1.04	8.00	-0.81
		8.00	-1.01	9.00	-1.18	8.50	-0.95
		8.50	-1.14	9.50	-1.32	9.00	-1.06
		9.00	-1.24	10.00	-1.43	9.50	-1.20
		10.00	-1.47	11.00	-1.57	10.00	-1.34
		11.00	-1.60	12.00	-1.65	11.00	-1.50
		12.00	-1.67	13.00	-1.70	12.00	-1.61
		13.00	-1.71	14.00	-1.73	13.00	-1.68
		14.00	-1.74	15.00	-1.81	14.00	-1.72
		15.00	-1.81	16.00	-1.85	15.00	-1.78
		16.00	-1.86	17.00	-1.89	16.00	-1.84
		17.00	-1.89	18.00	-1.99	17.00	-1.87
		18.00	-1.94			18.00	-1.96

(Continued)

(Sheet 1 of 2)

Table C5 (Concluded)

Profile T05P370		Profile T05P750		Profile T05P1450		Profile T05P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.80	0.97	-3.90	0.85	-1.50	0.12	-1.50	0.12
-3.50	0.95	-3.80	0.69	0.00	-0.24	0.00	-0.26
-3.30	0.57	-1.50	0.12	0.50	-0.36	1.00	-0.49
-1.50	0.12	0.00	-0.26	1.00	-0.49	1.50	-0.47
0.00	-0.22	0.50	-0.40	1.50	-0.57	2.00	-0.53
0.50	-0.31	1.00	-0.48	2.00	-0.55	2.50	-0.52
1.00	-0.34	1.50	-0.47	2.50	-0.55	3.00	-0.51
1.50	-0.38	2.00	-0.48	3.00	-0.57	3.50	-0.52
2.00	-0.43	2.50	-0.49	3.50	-0.57	4.00	-0.60
2.50	-0.46	3.00	-0.47	4.00	-0.61	4.50	-0.73
3.00	-0.51	3.50	-0.52	4.50	-0.68	5.00	-0.83
3.50	-0.58	4.00	-0.63	5.00	-0.74	5.50	-0.87
4.00	-0.68	4.50	-0.77	5.50	-0.74	6.00	-0.87
4.50	-0.72	5.00	-0.85	6.00	-0.76	6.50	-0.87
5.00	-0.75	5.50	-0.94	6.50	-0.83	7.00	-0.81
5.50	-0.74	6.00	-1.01	7.00	-0.88	7.50	-0.79
6.00	-0.76	6.50	-0.99	7.50	-0.88	8.00	-0.74
6.50	-0.76	7.00	-0.86	8.00	-0.83	8.50	-0.71
7.00	-0.73	7.50	-0.73	8.50	-0.79	9.00	-0.75
7.50	-0.72	8.00	-0.69	9.00	-0.80	9.50	-0.82
8.00	-0.74	8.50	-0.72	9.50	-0.86	10.00	-0.88
8.50	-0.78	9.00	-0.75	10.00	-0.92	11.00	-1.04
9.00	-0.84	9.50	-0.82	11.00	-1.05	12.00	-1.24
9.50	-0.93	10.00	-0.89	12.00	-1.22	13.00	-1.60
10.00	-1.04	11.00	-1.07	13.00	-1.58	14.00	-1.67
11.00	-1.32	12.00	-1.43	14.00	-1.66	15.00	-1.75
12.00	-1.50	13.00	-1.58	15.00	-1.74	16.00	-1.79
13.00	-1.62	14.00	-1.65	16.00	-1.80	17.00	-1.83
14.00	-1.67	15.00	-1.74	17.00	-1.84	18.00	-1.88
15.00	-1.76	16.00	-1.81	18.00	-1.88		
16.00	-1.83	17.00	-1.86				
17.00	-1.88	18.00	-1.92				
18.00	-1.95						

(Sheet 2 of 2)



Table C6

Profile Survey Data, Test T06

Profile T06P40		Profile T06P80		Profile T06P170		Profile T06P370	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.00	0.98	-3.00	1.00	-3.00	1.00	-3.30	0.97
-2.00	0.95	-2.00	0.94	-2.50	0.96	-3.10	0.52
-1.00	0.93	-1.70	0.86	-2.30	0.32	-2.00	0.25
-0.60	0.89	-1.40	0.11	-1.50	0.11	-1.00	-0.01
0.00	0.51	-1.00	0.02	-1.00	0.00	-0.50	-0.15
0.50	0.14	0.00	-0.16	-0.50	-0.10	0.00	-0.26
1.00	-0.21	0.50	-0.22	0.00	-0.18	0.50	-0.32
1.50	-0.42	1.00	-0.28	0.50	-0.24	1.00	-0.33
2.00	-0.53	1.50	-0.33	1.00	-0.27	1.50	-0.34
2.50	-0.60	2.00	-0.37	1.50	-0.32	2.00	-0.36
3.00	-0.68	2.50	-0.42	2.00	-0.33	2.50	-0.37
3.50	-0.76	3.00	-0.45	2.50	-0.43	3.00	-0.40
4.00	-0.86	3.50	-0.51	3.00	-0.56	3.50	-0.48
4.50	-0.92	4.00	-0.58	3.50	-0.64	4.00	-0.63
5.00	-0.97	4.50	-0.65	4.00	-0.64	4.50	-0.79
5.50	-1.02	5.00	-0.72	4.50	-0.61	5.00	-0.92
6.00	-1.07	5.50	-0.80	5.00	-0.60	5.50	-0.96
6.50	-1.09	6.00	-0.87	5.50	-0.63	6.00	-0.91
7.00	-1.12	6.50	-0.93	6.00	-0.68	6.50	-0.78
7.50	-1.14	7.00	-0.97	6.50	-0.71	7.00	-0.63
8.00	-1.13	7.50	-0.99	7.00	-0.76	7.50	-0.61
8.50	-1.12	8.00	-0.99	7.50	-0.85	8.00	-0.63
9.00	-1.11	8.50	-1.00	8.00	-0.90	8.50	-0.70
9.50	-1.08	9.00	-1.01	8.50	-0.91	9.00	-0.75
10.00	-1.05	9.50	-1.01	9.00	-0.93	9.50	-0.83
11.00	-1.17	10.00	-1.01	9.50	-0.96	10.00	-0.91
12.00	-1.51	11.00	-1.18	10.00	-1.02	11.00	-1.09
13.00	-1.75	11.50	-1.32	11.00	-1.15	12.00	-1.40
14.00	-1.85	12.00	-1.51	12.00	-1.51	13.00	-1.74
15.00	-1.91	13.00	-1.74	13.00	-1.73	14.00	-1.80
16.00	-1.95	14.00	-1.85	14.00	-1.83	15.00	-1.90
17.00	-2.00	15.00	-1.90	15.00	-1.90	16.00	-1.95
18.00	-2.04	16.00	-1.95	16.00	-1.95	17.00	-1.99
		17.00	-2.00	17.00	-2.00	18.00	-2.03
		18.00	-2.06	18.00	-2.06		

(Continued)

(Sheet 1 of 3)

Table C6 (Continued)

Profile T06P750		Profile T06P1450		Profile T06P1650		Profile T06G1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	1.00	-4.00	1.01	-4.00	1.00	0.00	-0.25
-3.80	1.00	-3.80	0.70	-3.80	0.70	0.50	-0.38
-3.70	0.67	-2.70	0.42	-2.70	0.42	1.00	-0.46
-1.50	0.12	-1.50	0.11	-1.50	0.11	1.50	-0.46
0.00	-0.26	0.00	-0.25	0.00	-0.26	2.00	-0.48
0.50	-0.29	0.50	-0.36	0.50	-0.39	2.50	-0.48
1.00	-0.36	1.00	-0.48	1.00	-0.46	3.00	-0.41
1.50	-0.39	1.50	-0.45	1.50	-0.42	3.50	-0.40
2.00	-0.47	2.00	-0.49	2.00	-0.48	4.00	-0.45
2.50	-0.50	2.50	-0.57	2.50	-0.53	4.50	-0.53
3.00	-0.42	3.00	-0.58	3.00	-0.52	5.00	-0.69
3.50	-0.42	3.50	-0.48	3.50	-0.43	5.50	-0.83
4.00	-0.48	4.00	-0.45	4.00	-0.43	6.00	-0.78
4.50	-0.59	4.50	-0.53	4.50	-0.51	6.50	-0.63
5.00	-0.82	5.00	-0.69	5.00	-0.73	7.00	-0.55
5.50	-1.00	5.50	-0.89	5.50	-0.88	7.50	-0.55
6.00	-1.06	6.00	-1.00	6.00	-0.97	8.00	-0.58
6.50	-0.94	6.50	-0.96	6.50	-0.90	8.50	-0.67
7.00	-0.78	7.00	-0.76	7.00	-0.73	9.00	-0.74
7.50	-0.57	7.50	-0.60	7.50	-0.58	9.50	-0.83
8.00	-0.58	8.00	-0.59	8.00	-0.57	10.00	-0.88
8.50	-0.62	8.50	-0.62	8.50	-0.62	11.00	-1.17
9.00	-0.68	9.00	-0.68	9.00	-0.62	12.00	-1.41
9.50	-0.75	9.50	-0.75	9.50	-0.74	13.00	-1.67
10.00	-0.83	10.00	-0.82	10.00	-0.82	14.00	-1.85
11.00	-1.01	11.00	-1.02	11.00	-1.00	15.00	-1.89
12.00	-1.42	12.00	-1.42	12.00	-1.41	16.00	-1.97
13.00	-1.70	13.00	-1.72	13.00	-1.70	17.00	-1.96
14.00	-1.84	14.00	-1.83	14.00	-1.80	18.00	-2.01
15.00	-1.88	15.00	-1.87	15.00	-1.86		
16.00	-1.95	16.00	-1.91	16.00	-1.92		
17.00	-1.98	17.00	-1.96	17.00	-1.96		
18.00	-2.04	18.00	-2.01	18.00	-1.98		

(Continued)

(Sheet 2 of 3)

Table C6 (Concluded)

Profile T06C1650		Profile T06P1850	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
0.00	-0.25	-4.00	1.00
0.50	-0.33	-3.90	0.72
1.00	-0.46	-1.50	0.12
1.50	-0.58	0.00	-0.26
2.00	-0.58	0.50	-0.39
2.50	-0.60	1.00	-0.44
3.00	-0.67	1.50	-0.45
3.50	-0.76	2.00	-0.45
4.00	-0.81	2.50	-0.46
4.50	-0.77	3.00	-0.42
5.00	-0.72	3.50	-0.40
5.50	-0.81	4.00	-0.47
6.00	-1.05	4.50	-0.61
6.50	-1.25	5.00	-0.78
7.00	-1.33	5.50	-0.89
7.50	-1.23	6.00	-0.91
8.00	-0.98	6.50	-0.84
8.50	-0.74	7.00	-0.69
9.00	-0.70	7.50	-0.57
9.50	-0.75	8.00	-0.57
10.00	-0.79	8.50	-0.61
11.00	-0.90	9.00	-0.66
12.00	-1.10	9.50	-0.74
13.00	-1.56	10.00	-0.82
14.00	-1.77	11.00	-1.00
15.00	-1.84	12.00	-1.46
16.00	-1.89	13.00	-1.73
17.00	-1.94	14.00	-1.79
18.00	-2.00	15.00	-1.87
		16.00	-1.91
		17.00	-1.97
		18.00	-2.02

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Table C7

Profile Survey Data, Test T07

Profile T07START		Profile T07P40		Profile T07P80		Profile T07P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.93	-3.00	0.93	-3.00	0.92	-3.00	0.92
-4.00	0.93	-2.00	0.91	-2.00	0.91	-2.00	0.91
-3.00	0.93	-1.00	0.91	-1.00	0.91	-1.50	0.88
-2.00	0.91	-0.50	0.83	-0.60	0.88	-1.30	0.22
-1.00	0.90	0.00	0.52	-0.50	0.13	-1.00	0.16
0.00	0.86	0.30	0.08	0.00	0.03	0.00	-0.02
1.00	0.70	0.50	0.03	0.50	-0.05	0.50	-0.10
2.00	0.38	1.00	-0.07	1.00	-0.12	1.00	-0.16
3.00	0.10	1.50	-0.15	1.50	-0.19	1.50	-0.20
4.00	-0.15	2.00	-0.21	2.00	-0.25	2.00	-0.25
5.00	-0.42	2.50	-0.27	2.50	-0.29	2.50	-0.31
6.00	-0.68	3.00	-0.30	3.00	-0.30	3.00	-0.36
7.00	-0.95	3.50	-0.35	3.50	-0.37	3.50	-0.39
7.87	-1.15	4.00	-0.40	4.00	-0.53	4.00	-0.48
8.00	-1.18	4.50	-0.42	4.50	-0.69	4.50	-0.63
9.00	-1.40	5.00	-0.46	5.00	-0.68	5.00	-0.77
10.00	-1.62	5.50	-0.48	5.50	-0.61	5.50	-0.84
11.00	-1.81	6.00	-0.57	6.00	-0.57	6.00	-0.83
12.00	-1.96	6.50	-0.68	6.50	-0.62	6.50	-0.71
13.00	-2.10	7.00	-0.79	7.00	-0.66	7.00	-0.65
14.00	-2.18	7.50	-0.92	7.50	-0.74	7.50	-0.63
		8.00	-1.05	8.00	-0.80	8.00	-0.67
		8.50	-1.17	8.50	-0.91	8.50	-0.75
		9.00	-1.23	9.00	-1.00	9.00	-0.83
		9.50	-1.32	9.50	-1.14	9.50	-0.93
		10.00	-1.39	10.00	-1.26	10.00	-1.07
		11.00	-1.52	11.00	-1.45	11.00	-1.31
		12.00	-1.72	12.00	-1.64	12.00	-1.57
		13.00	-1.92	13.00	-1.87	13.00	-1.83
		14.00	-1.99	14.00	-1.99	14.00	-1.96
		15.00	-2.04	15.00	-2.02	15.00	-2.00
		16.00	-2.07	16.00	-2.07	16.00	-2.05
		17.00	-2.13	17.00	-2.11	17.00	-2.10
		18.00	-2.15	18.00	-2.15	18.00	-2.13

(Continued)

(Sheet 1 of 3)

Table C7 (Continued)

Profile T07P370		Profile T07P750		Profile T07P1450		Profile T07P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-3.00	0.92	-3.50	0.93	-3.80	0.94	-4.00	0.99
-2.20	0.90	-3.00	0.91	-3.50	0.91	-3.50	0.91
-2.10	0.28	-2.70	0.90	-3.20	0.54	-3.40	0.59
-1.00	0.07	-2.50	0.38	-2.00	0.24	-1.50	0.12
-0.50	-0.02	-1.50	0.12	-1.00	-0.01	0.00	-0.26
0.00	-0.09	-1.00	0.02	0.00	-0.25	0.50	-0.35
0.50	-0.16	-0.50	-0.09	0.50	-0.31	1.00	-0.34
1.00	-0.20	0.00	-0.19	1.00	-0.35	1.50	-0.33
1.50	-0.22	0.50	-0.20	1.50	-0.32	2.00	-0.34
2.00	-0.26	1.00	-0.23	2.00	-0.32	2.50	-0.38
2.50	-0.33	1.50	-0.25	2.50	-0.39	3.00	-0.49
3.00	-0.43	2.00	-0.30	3.00	-0.49	3.50	-0.58
3.50	-0.45	2.50	-0.34	3.50	-0.57	4.00	-0.57
4.00	-0.44	3.00	-0.43	4.00	-0.56	4.50	-0.50
4.50	-0.47	3.50	-0.48	4.50	-0.48	5.00	-0.49
5.00	-0.65	4.00	-0.46	5.00	-0.46	5.50	-0.51
5.50	-0.88	4.50	-0.45	5.50	-0.52	6.00	-0.69
6.00	-1.02	5.00	-0.50	6.00	-0.75	6.50	-0.93
6.50	-1.04	5.50	-0.67	6.50	-0.99	7.00	-1.13
7.00	-0.89	6.00	-0.92	7.00	-1.10	7.50	-1.18
7.50	-0.66	6.50	-1.06	7.50	-1.13	8.00	-1.15
8.00	-0.61	7.00	-1.07	8.00	-1.05	8.50	-1.03
8.50	-0.66	7.50	-0.95	8.50	-0.88	9.00	-0.80
9.00	-0.71	8.00	-0.73	9.00	-0.72	9.50	-0.68
9.50	-0.78	8.50	-0.64	9.50	-0.67	10.00	-0.70
10.00	-0.88	9.00	-0.65	10.00	-0.70	11.00	-0.81
11.00	-1.13	9.50	-0.71	11.00	-0.83	12.00	-0.97
12.00	-1.48	10.00	-0.77	12.00	-1.00	13.00	-1.32
13.00	-1.79	11.00	-0.95	13.00	-1.38	14.00	-1.79
14.00	-1.93	12.00	-1.27	14.00	-1.83	15.00	-1.92
15.00	-1.99	13.00	-1.68	15.00	-1.91	16.00	-1.99
16.00	-2.02	14.00	-1.90	16.00	-1.97	17.00	-2.06
17.00	-2.08	15.00	-1.96	17.00	-2.02	18.00	-1.98
18.00	-2.11	16.00	-1.98	18.00	-2.07		
		17.00	-2.06				
		18.00	-2.09				

(Continued)

(Sheet 2 of 3)

Table C7 (Concluded)

Profile T07G1650		Profile T07C1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
0.00	-0.26	0.00	-0.26
0.50	-0.32	0.50	-0.31
1.00	-0.36	1.00	-0.41
1.50	-0.39	1.50	-0.47
2.00	-0.41	2.00	-0.47
2.50	-0.48	2.50	-0.52
3.00	-0.56	3.00	-0.53
3.50	-0.62	3.50	-0.64
4.00	-0.60	4.00	-0.74
4.50	-0.52	4.50	-0.77
5.00	-0.50	5.00	-0.71
5.50	-0.53	5.50	-0.70
6.00	-0.71	6.00	-0.68
6.50	-0.98	6.50	-0.90
7.00	-1.08	7.00	-1.12
7.50	-1.10	7.50	-1.31
8.00	-1.00	8.00	-1.39
8.50	-0.76	8.50	-1.28
9.00	-0.68	9.00	-1.05
9.50	-0.69	9.50	-0.84
10.00	-0.71	10.00	-0.73
11.00	-0.86	11.00	-0.76
12.00	-1.09	12.00	-0.90
13.00	-1.34	13.00	-1.10
14.00	-1.66	14.00	-1.62
15.00	-1.90	15.00	-1.97
16.00	-1.94	16.00	-1.98
17.00	-1.99	17.00	-2.02
18.00	-2.04	18.00	-2.05

(Sheet 3 of 3)

Table C8

Profile Survey Data, Test T08

Profile T08START		Profile T08P40		Profile T08P80		Profile T08P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.97	-4.00	0.96	-4.00	0.98	-4.00	0.97
-4.00	0.97	-3.00	0.93	-3.00	0.92	-3.00	0.92
-3.00	0.93	-2.00	0.89	-2.00	0.88	-2.00	0.84
-2.00	0.88	-1.00	0.83	-1.20	0.81	-1.50	0.33
-1.00	0.82	0.00	0.56	-0.90	0.65	-1.00	0.23
0.00	0.79	0.50	0.16	-0.50	0.17	0.00	0.03
1.00	0.63	1.00	0.04	0.00	0.06	0.50	-0.03
2.00	0.39	1.50	-0.05	0.50	0.00	1.00	-0.09
3.00	0.17	2.00	-0.14	1.00	-0.07	1.50	-0.16
4.00	-0.08	2.50	-0.24	1.50	-0.14	2.00	-0.21
5.00	-0.35	3.00	-0.29	2.00	-0.21	2.50	-0.29
6.00	-0.59	3.50	-0.34	2.50	-0.27	3.00	-0.35
7.00	-0.84	4.00	-0.39	3.00	-0.33	3.50	-0.40
7.87	-1.07	4.50	-0.44	3.50	-0.38	4.00	-0.44
8.00	-1.10	5.00	-0.51	4.00	-0.43	4.50	-0.48
9.00	-1.34	5.50	-0.55	4.50	-0.45	5.00	-0.55
10.00	-1.59	6.00	-0.61	5.00	-0.50	5.50	-0.61
11.00	-1.82	6.50	-0.65	5.50	-0.57	6.00	-0.68
12.00	-2.01	7.00	-0.75	6.00	-0.64	6.50	-0.71
13.00	-2.16	7.50	-0.85	6.50	-0.69	7.00	-0.72
14.00	-2.20	8.00	-0.94	7.00	-0.71	7.50	-0.72
		8.50	-1.05	7.50	-0.75	8.00	-0.77
		9.00	-1.15	8.00	-0.83	8.50	-0.84
		9.50	-1.25	8.50	-0.93	9.00	-0.91
		10.00	-1.37	9.00	-1.02	9.50	-1.01
		11.00	-1.57	9.50	-1.13	10.00	-1.12
		12.00	-1.77	10.00	-1.26	11.00	-1.37
		13.00	-1.95	11.00	-1.49	12.00	-1.64
		14.00	-2.00	12.00	-1.70	13.00	-1.84
		15.00	-2.05	13.00	-1.89	14.00	-1.96
		16.00	-2.10	14.00	-1.99	15.00	-2.01
		17.00	-2.13	15.00	-2.03	16.00	-2.07
		18.00	-2.15	16.00	-2.08	17.00	-2.11
				17.00	-2.12	18.00	-2.13
				18.00	-2.14		

(Continued)

(Sheet 1 of 2)

Table C8 (Concluded)

Profile T08P370		Profile T08P750		Profile T08P1450		Profile T08P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	0.97	-4.00	0.98	-1.50	0.11	-4.00	0.74
-3.00	0.90	-3.70	0.89	0.00	-0.28	-1.50	0.12
-2.50	0.48	-3.50	0.62	0.50	-0.38	0.00	-0.26
-2.00	0.35	-1.50	0.12	1.00	-0.41	0.50	-0.41
-1.00	0.14	0.00	-0.19	1.50	-0.45	1.00	-0.44
0.00	-0.04	0.50	-0.24	2.00	-0.47	1.50	-0.47
0.50	-0.10	1.00	-0.29	2.50	-0.47	2.00	-0.48
1.00	-0.17	1.50	-0.33	3.00	-0.52	2.50	-0.49
1.50	-0.24	2.00	-0.36	3.50	-0.53	3.00	-0.53
2.00	-0.29	2.50	-0.39	4.00	-0.59	3.50	-0.56
2.50	-0.34	3.00	-0.43	4.50	-0.62	4.00	-0.59
3.00	-0.38	3.50	-0.46	5.00	-0.66	4.50	-0.64
3.50	-0.43	4.00	-0.50	5.50	-0.69	5.00	-0.67
4.00	-0.47	4.50	-0.54	6.00	-0.70	5.50	-0.68
4.50	-0.50	5.00	-0.59	6.50	-0.74	6.00	-0.69
5.00	-0.55	5.50	-0.64	7.00	-0.80	6.50	-0.73
5.50	-0.62	6.00	-0.67	7.50	-0.90	7.00	-0.81
6.00	-0.69	6.50	-0.73	8.00	-0.98	7.50	-0.88
6.50	-0.73	7.00	-0.79	8.50	-0.98	8.00	-0.98
7.00	-0.74	7.50	-0.86	9.00	-0.93	8.50	-1.01
7.50	-0.76	8.00	-0.86	9.50	-0.88	9.00	-0.97
8.00	-0.76	8.50	-0.84	10.00	-0.89	9.50	-0.94
8.50	-0.78	9.00	-0.83	11.00	-0.92	10.00	-0.87
9.00	-0.82	9.50	-0.83	12.00	-1.05	11.00	-0.90
9.50	-0.88	10.00	-0.88	13.00	-1.21	12.00	-1.02
10.00	-0.97	11.00	-1.00	14.00	-1.49	13.00	-1.17
11.00	-1.18	12.00	-1.17	15.00	-1.84	14.00	-1.41
12.00	-1.45	13.00	-1.48	16.00	-1.91	15.00	-1.79
13.00	-1.73	14.00	-1.80	17.00	-1.96	16.00	-1.88
14.00	-1.89	15.00	-1.91	18.00	-2.02	17.00	-1.95
15.00	-1.96	16.00	-1.97			18.00	-1.98
16.00	-2.01	17.00	-2.01				
17.00	-2.05	18.00	-2.07				
18.00	-2.09						

(Sheet 2 of 2)



Table C9

Profile Survey Data, Test T09

Profile T09START		Profile T09P40		Profile T09P80		Profile T09P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.87	-4.00	0.96	-4.00	0.89	-4.00	0.89
-4.00	0.89	-3.00	0.93	-3.00	0.86	-3.00	0.81
-3.00	0.87	-2.00	0.89	-2.00	0.81	-2.00	0.85
-2.00	0.86	-1.00	0.83	-1.00	0.81	-1.00	0.79
-1.00	0.82	-0.50	0.56	-0.80	0.70	-0.70	0.19
0.00	0.80	0.00	0.16	-0.30	0.23	0.00	0.05
1.00	0.61	0.50	0.04	0.00	0.09	0.50	-0.02
2.00	0.31	1.00	-0.05	0.50	0.03	1.00	-0.08
3.00	0.08	1.50	-0.14	1.00	-0.04	1.50	-0.16
4.00	-0.17	2.00	-0.24	1.50	-0.12	2.00	-0.22
5.00	-0.41	2.50	-0.29	2.00	-0.21	2.50	-0.27
6.00	-0.62	3.00	-0.34	2.50	-0.26	3.00	-0.32
7.00	-0.87	3.50	-0.39	3.00	-0.31	3.50	-0.37
7.87	-1.10	4.00	-0.44	3.50	-0.36	4.00	-0.42
8.00	-1.14	4.50	-0.51	4.00	-0.41	4.50	-0.46
9.00	-1.36	5.00	-0.55	4.50	-0.45	5.00	-0.50
10.00	-1.60	5.50	-0.61	5.00	-0.49	5.50	-0.53
11.00	-1.80	6.00	-0.65	5.50	-0.55	6.00	-0.56
12.00	-1.98	6.50	-0.75	6.00	-0.58	6.50	-0.61
13.00	-2.11	7.00	-0.85	6.50	-0.60	7.00	-0.65
14.00	-2.16	7.50	-0.94	7.00	-0.67	7.50	-0.67
		8.00	-1.05	7.50	-0.72	8.00	-0.72
		8.50	-1.15	8.00	-0.80	8.50	-0.80
		9.00	-1.25	8.50	-0.89	9.00	-0.89
		9.50	-1.37	9.00	-0.99	9.50	-1.04
		10.00	-1.57	9.50	-1.15	10.00	-1.21
		11.00	-1.77	10.00	-1.29	11.00	-1.51
		12.00	-1.95	11.00	-1.56	12.00	-1.77
		13.00	-2.00	12.00	-1.80	13.00	-1.99
		14.00	-2.05	13.00	-2.00	14.00	-2.07
		15.00	-2.10	14.00	-2.08	15.00	-2.11
		16.00	-2.13	15.00	-2.12	16.00	-2.14
		17.00	-2.15	16.00	-2.15	17.00	-2.16
		18.00	-2.18	17.00	-2.16	18.00	-2.17
				18.00	-2.18		

(Continued)

(Sheet 1 of 3)

Table C9 (Continued)

Profile T09P370		Profile T09P750		Profile T09P1450		Profile T09P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	0.89	-4.00	0.89	-4.00	0.89	-4.00	0.89
-3.00	0.85	-3.00	0.86	-3.00	0.86	-3.20	0.85
-2.00	0.86	-2.20	0.86	-2.60	0.85	-3.00	0.51
-1.50	0.80	-2.00	0.43	-2.40	0.36	-1.00	0.03
-1.30	0.29	-1.00	0.15	-1.00	0.05	0.00	-0.17
-0.50	0.11	0.00	-0.05	0.00	-0.13	0.50	-0.20
0.00	0.00	0.50	-0.11	0.50	-0.22	1.00	-0.24
0.50	-0.07	1.00	-0.18	1.00	-0.17	1.50	-0.27
1.00	-0.14	1.50	-0.24	1.50	-0.21	2.00	-0.31
1.50	-0.20	2.00	-0.29	2.00	-0.33	2.50	-0.35
2.00	-0.24	2.50	-0.33	2.50	-0.36	3.00	-0.40
2.50	-0.30	3.00	-0.37	3.00	-0.40	3.50	-0.43
3.00	-0.35	3.50	-0.41	3.50	-0.44	4.00	-0.47
3.50	-0.38	4.00	-0.43	4.00	-0.47	4.50	-0.50
4.00	-0.43	4.50	-0.49	4.50	-0.50	5.00	-0.52
4.50	-0.45	5.00	-0.53	5.00	-0.53	5.50	-0.55
5.00	-0.51	5.50	-0.55	5.50	-0.56	6.00	-0.59
5.50	-0.54	6.00	-0.58	6.00	-0.60	6.50	-0.67
6.00	-0.59	6.50	-0.63	6.50	-0.65	7.00	-0.74
6.50	-0.63	7.00	-0.72	7.00	-0.69	7.50	-0.75
7.00	-0.66	7.50	-0.69	7.50	-0.74	8.00	-0.76
7.50	-0.68	8.00	-0.69	8.00	-0.80	8.50	-0.74
8.00	-0.69	8.50	-0.73	8.50	-0.76	9.00	-0.70
8.50	-0.74	9.00	-0.76	9.00	-0.73	9.50	-0.73
9.00	-0.81	9.50	-0.84	9.50	-0.77	10.00	-0.80
9.50	-0.92	10.00	-0.91	10.00	-0.82	11.00	-0.97
10.00	-1.06	11.00	-1.18	11.00	-1.00	12.00	-1.27
11.00	-1.39	12.00	-1.57	12.00	-1.30	13.00	-1.70
12.00	-1.72	13.00	-1.89	13.00	-1.75	14.00	-1.94
13.00	-1.94	14.00	-1.99	14.00	-1.94	15.00	-2.00
14.00	-2.05	15.00	-2.05	15.00	-2.01	16.00	-2.04
15.00	-2.09	16.00	-2.11	16.00	-2.04	17.00	-2.08
16.00	-2.13	17.00	-2.12	17.00	-2.09	18.00	-2.11
17.00	-2.15	18.00	-2.14	18.00	-2.12		
18.00	-2.16						

(Continued)

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Table C9 (Concluded)

Profile T09P1850		Profile T09G1850		Profile T09C1850	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	0.89	0.00	-0.19	0.00	-0.21
-3.20	0.85	0.50	-0.26	0.50	-0.31
-3.00	0.51	1.00	-0.30	1.00	-0.33
-1.00	0.03	1.50	-0.34	1.50	-0.39
0.00	-0.19	2.00	-0.38	2.00	-0.43
0.50	-0.23	2.50	-0.42	2.50	-0.46
1.00	-0.26	3.00	-0.45	3.00	-0.50
1.50	-0.30	3.50	-0.52	3.50	-0.53
2.00	-0.31	4.00	-0.57	4.00	-0.59
2.50	-0.34	4.50	-0.62	4.50	-0.64
3.00	-0.38	5.00	-0.65	5.00	-0.69
3.50	-0.42	5.50	-0.66	5.50	-0.74
4.00	-0.47	6.00	-0.66	6.00	-0.77
4.50	-0.49	6.50	-0.71	6.50	-0.78
5.00	-0.51	7.00	-0.77	7.00	-0.81
5.50	-0.55	7.50	-0.81	7.50	-0.86
6.00	-0.60	8.00	-0.84	8.00	-0.90
6.50	-0.66	8.50	-0.81	8.50	-0.90
7.00	-0.73	9.00	-0.79	9.00	-0.88
7.50	-0.71	9.50	-0.81	9.50	-0.86
8.00	-0.72	10.00	-0.87	10.00	-0.90
8.50	-0.70	11.00	-1.05	10.50	-0.94
9.00	-0.68	12.00	-1.31	11.00	-1.02
9.50	-0.73	13.00	-1.71	12.00	-1.26
10.00	-0.79	14.00	-1.93	13.00	-1.55
11.00	-0.97	15.00	-1.97	14.00	-1.97
12.00	-1.23	16.00	-2.05	15.00	-2.05
13.00	-1.66	17.00	-2.07	16.00	-2.10
14.00	-1.92	18.00	-2.10	17.00	-2.15
15.00	-1.98			18.00	-2.18
16.00	-2.04				
17.00	-2.09				
18.00	-2.10				

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Table C10

Profile Survey Data, Test T10

Profile T10START		Profile T10P40		Profile T10P80		Profile T10P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.87	-4.00	0.86	-4.00	0.86	-4.00	0.86
-4.00	0.89	-0.66	0.86	-3.00	0.86	-3.00	0.86
-3.00	0.87	-0.65	0.82	-2.00	0.86	-0.65	0.86
-2.00	0.86	-0.55	0.81	-0.66	0.86	-0.65	0.03
-1.00	0.86	0.00	0.59	-0.65	0.20	-0.55	0.01
0.00	0.79	0.30	0.05	-0.55	0.18	0.00	-0.08
1.00	0.52	0.50	0.01	0.00	0.08	0.50	-0.16
2.00	0.32	1.00	-0.07	0.50	-0.01	1.00	-0.22
3.00	0.10	1.50	-0.14	1.00	-0.10	1.50	-0.26
4.00	-0.14	2.00	-0.21	1.50	-0.17	2.00	-0.29
5.00	-0.38	2.50	-0.25	2.00	-0.21	2.50	-0.33
6.00	-0.60	3.00	-0.29	2.50	-0.28	3.00	-0.40
7.00	-0.84	3.50	-0.33	3.00	-0.32	3.50	-0.49
7.87	-1.04	4.00	-0.39	3.50	-0.35	4.00	-0.51
8.00	-1.07	4.50	-0.47	4.00	-0.42	4.50	-0.55
9.00	-1.32	5.00	-0.52	4.50	-0.55	5.00	-0.74
10.00	-1.59	5.50	-0.53	5.00	-0.64	5.50	-0.79
11.00	-1.81	6.00	-0.54	5.50	-0.61	6.00	-0.73
12.00	-2.05	6.50	-0.61	6.00	-0.58	6.50	-0.63
13.00	-2.15	7.00	-0.72	6.50	-0.60	7.00	-0.62
14.00	-2.19	7.50	-0.83	7.00	-0.64	7.50	-0.64
		8.00	-0.98	7.50	-0.73	8.00	-0.70
		8.50	-1.13	8.00	-0.81	8.50	-0.77
		9.00	-1.24	8.50	-0.91	9.00	-0.84
		9.50	-1.37	9.00	-1.03	9.50	-0.99
		10.00	-1.49	9.50	-1.20	10.00	-1.14
		10.50	-1.57	10.00	-1.36	10.50	-1.33
		11.00	-1.64	10.50	-1.48	11.00	-1.47
		12.00	-1.72	11.00	-1.57	12.00	-1.68
		13.00	-1.82	12.00	-1.69	13.00	-1.77
		14.00	-1.90	13.00	-1.78	14.00	-1.88
		15.00	-2.01	14.00	-1.88	15.00	-1.99
		16.00	-2.10	15.00	-2.00	16.00	-2.08
		17.00	-2.14	16.00	-2.09	17.00	-2.13
		18.00	-2.17	17.00	-2.14	18.00	-2.16
				18.00	-2.17		

(Continued)

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Table C10 (Continued)

Profile	T10P370	Profile	T10P750	Profile	T10P1450	Profile	T10P1650
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	0.86	-4.00	0.86	-4.00	0.86	-4.00	0.86
-3.00	0.86	-3.00	0.86	-3.00	0.86	-0.65	0.85
-2.00	0.86	-0.65	0.86	-0.65	0.86	-0.65	-0.12
-0.65	0.86	-0.65	-0.12	-0.65	-0.12	-0.55	-0.14
-0.65	-0.12	-0.55	-0.14	-0.55	-0.14	0.00	-0.26
-0.55	-0.14	0.00	-0.24	0.00	-0.24	0.50	-0.39
0.00	-0.24	0.50	-0.34	0.50	-0.34	1.00	-0.51
0.50	-0.26	1.00	-0.43	1.00	-0.43	1.50	-0.55
1.00	-0.29	1.50	-0.45	1.50	-0.56	2.00	-0.51
1.50	-0.34	2.00	-0.45	2.00	-0.52	2.50	-0.48
2.00	-0.38	2.50	-0.47	2.50	-0.50	3.00	-0.54
2.50	-0.39	3.00	-0.47	3.00	-0.51	3.50	-0.61
3.00	-0.39	3.50	-0.48	3.50	-0.60	4.00	-0.67
3.50	-0.44	4.00	-0.54	4.00	-0.66	4.50	-0.70
4.00	-0.48	4.50	-0.68	4.50	-0.68	5.00	-0.81
4.50	-0.57	5.00	-0.78	5.00	-0.83	5.50	-1.01
5.00	-0.78	5.50	-0.90	5.50	-0.98	6.00	-1.11
5.50	-0.93	6.00	-0.96	6.00	-1.07	6.50	-1.09
6.00	-0.93	6.50	-0.93	6.50	-1.04	7.00	-0.95
6.50	-0.77	7.00	-0.83	7.00	-0.93	7.50	-0.76
7.00	-0.65	7.50	-0.73	7.50	-0.74	8.00	-0.72
7.50	-0.63	8.00	-0.70	8.00	-0.71	8.50	-0.75
8.00	-0.66	8.50	-0.73	8.50	-0.74	9.00	-0.78
8.50	-0.70	9.00	-0.76	9.00	-0.78	9.50	-0.84
9.00	-0.77	9.50	-0.84	9.50	-0.83	10.00	-0.94
9.50	-0.84	10.00	-0.90	10.00	-0.94	10.50	-0.99
10.00	-0.94	10.50	-0.98	10.50	-0.96	11.00	-1.08
10.50	-1.10	11.00	-1.11	11.00	-1.06	12.00	-1.17
11.00	-1.34	12.00	-1.40	12.00	-1.25	13.00	-1.54
12.00	-1.63	13.00	-1.76	13.00	-1.59	14.00	-1.88
13.00	-1.79	14.00	-1.86	14.00	-1.87	15.00	-1.94
14.00	-1.87	15.00	-1.95	15.00	-1.93	16.00	-1.98
15.00	-1.97	16.00	-2.03	16.00	-1.98	17.00	-2.04
16.00	-2.05	17.00	-2.10	17.00	-2.04	18.00	-2.09
17.00	-2.12	18.00	-2.15	18.00	-2.11		
18.00	-2.14						

(Continued)

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Table C10 (Concluded)

Profile T10P1850		Profile T10G1850		Profile T10C1850	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	0.86	0.00	-0.26	0.00	-0.26
-0.65	0.85	1.00	-0.49	1.00	-0.49
-0.65	-0.12	1.50	-0.62	1.50	-0.57
-0.55	-0.14	2.00	-0.57	2.00	-0.53
0.00	-0.26	2.50	-0.55	2.50	-0.51
0.50	-0.39	3.00	-0.58	3.00	-0.55
1.00	-0.49	3.50	-0.62	3.50	-0.57
1.50	-0.51	4.00	-0.65	4.00	-0.68
2.00	-0.49	4.50	-0.75	4.50	-0.83
2.50	-0.49	5.00	-0.97	5.00	-1.00
3.00	-0.54	5.50	-1.16	5.50	-1.07
3.50	-0.63	6.00	-1.25	6.00	-1.00
4.00	-0.66	6.50	-1.24	6.50	-0.82
4.50	-0.69	7.00	-1.11	7.00	-0.74
5.00	-0.90	7.50	-0.95	7.50	-0.73
5.50	-1.05	8.00	-0.78	8.00	-0.74
6.00	-1.09	8.50	-0.78	8.50	-0.77
6.50	-1.04	9.00	-0.81	9.00	-0.83
7.00	-0.95	9.50	-0.86	9.50	-0.93
7.50	-0.79	10.00	-0.92	10.00	-0.99
8.00	-0.73	10.50	-0.98	10.50	-1.02
8.50	-0.75	11.00	-1.03	11.00	-1.06
9.00	-0.80	12.00	-1.17	12.00	-1.20
9.50	-0.88	13.00	-1.38	13.00	-1.44
10.00	-0.95	14.00	-1.74	14.00	-1.81
10.50	-0.96	15.00	-1.94	15.00	-1.93
11.00	-1.01	16.00	-1.96	16.00	-1.96
12.00	-1.19	17.00	-2.03	17.00	-2.04
13.00	-1.48	18.00	-2.08	18.00	-2.09
14.00	-1.85				
15.00	-1.92				
16.00	-1.97				
17.00	-2.03				
18.00	-2.08				

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Table C11

Profile Survey Data, Test T11

Profile T11START		Profile T11P40		Profile T11P80		Profile T11P170	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	0.94	-4.00	0.94	-4.00	0.94	-4.00	0.94
-4.00	0.94	-0.66	0.94	-3.00	0.94	-3.00	0.94
-3.00	0.94	-0.65	0.94	-2.00	0.94	-0.65	0.94
-2.00	0.94	-0.55	0.93	-0.66	0.94	-0.65	0.19
-1.00	0.94	0.00	0.69	-0.65	0.81	-0.55	0.17
0.00	0.94	0.50	0.09	-0.55	0.78	0.00	0.08
1.00	0.67	1.00	0.00	0.00	0.61	0.50	0.01
2.00	0.39	1.50	-0.08	0.10	0.14	1.00	-0.08
3.00	0.11	2.00	-0.16	0.50	0.05	1.50	-0.15
4.00	-0.14	2.50	-0.23	1.00	-0.02	2.00	-0.23
5.00	-0.40	3.00	-0.31	1.50	-0.11	2.50	-0.26
6.00	-0.63	3.50	-0.35	2.00	-0.20	3.00	-0.31
7.00	-0.87	4.00	-0.40	2.50	-0.25	3.50	-0.35
7.87	-1.08	4.50	-0.43	3.00	-0.31	4.00	-0.39
8.00	-1.11	5.00	-0.48	3.50	-0.36	4.50	-0.45
9.00	-1.33	5.50	-0.52	4.00	-0.42	5.00	-0.50
10.00	-1.60	6.00	-0.57	4.50	-0.44	5.50	-0.53
11.00	-1.82	6.50	-0.64	5.00	-0.47	6.00	-0.56
12.00	-2.02	7.00	-0.73	5.50	-0.53	6.50	-0.60
13.00	-2.19	7.50	-0.80	6.00	-0.58	7.00	-0.63
14.00	-2.20	8.00	-0.90	6.50	-0.63	7.50	-0.69
		8.50	-1.02	7.00	-0.65	8.00	-0.74
		9.00	-1.12	7.50	-0.73	8.50	-0.82
		9.50	-1.24	8.00	-0.80	9.00	-0.90
		10.00	-1.36	8.50	-0.92	9.50	-1.03
		10.50	-1.46	9.00	-1.03	10.00	-1.19
		11.00	-1.59	9.50	-1.17	10.50	-1.34
		12.00	-1.81	10.00	-1.30	11.00	-1.50
		13.00	-1.99	10.50	-1.42	12.00	-1.76
		14.00	-2.04	11.00	-1.54	13.00	-1.96
		15.00	-2.09	12.00	-1.80	14.00	-2.02
		16.00	-2.12	13.00	-1.98	15.00	-2.07
		17.00	-2.16	14.00	-2.04	16.00	-2.12
		18.00	-2.18	15.00	-2.08	17.00	-2.14
				16.00	-2.12	18.00	-2.17
				17.00	-2.15		
				18.00	-2.18		

(Continued)

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Table C11 (Continued)

Profile T11P370		Profile T11P750		Profile T11P1450		Profile T11P1650	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-4.00	0.94	-4.00	0.94	-4.00	0.94	-4.00	0.94
-3.00	0.94	-3.00	0.94	-3.00	0.94	-0.65	0.94
-2.00	0.94	-0.65	0.94	-0.65	0.94	-0.65	-0.12
-0.65	0.94	-0.65	-0.12	-0.65	-0.12	-0.55	-0.14
-0.65	0.04	-0.55	-0.13	-0.55	-0.14	0.00	-0.24
-0.55	0.03	0.00	-0.21	0.00	-0.24	0.50	-0.33
0.00	-0.04	0.50	-0.25	0.50	-0.31	1.00	-0.42
0.50	-0.12	1.00	-0.30	1.00	-0.38	1.50	-0.43
1.00	-0.18	1.50	-0.34	1.50	-0.40	2.00	-0.44
1.50	-0.22	2.00	-0.37	2.00	-0.43	2.50	-0.45
2.00	-0.28	2.50	-0.39	2.50	-0.45	3.00	-0.47
2.50	-0.38	3.00	-0.41	3.00	-0.47	3.50	-0.50
3.00	-0.38	3.50	-0.44	3.50	-0.50	4.00	-0.53
3.50	-0.42	4.00	-0.47	4.00	-0.53	4.50	-0.56
4.00	-0.45	4.50	-0.50	4.50	-0.56	5.00	-0.59
4.50	-0.49	5.00	-0.55	5.00	-0.59	5.50	-0.67
5.00	-0.53	5.50	-0.59	5.50	-0.64	6.00	-0.75
5.50	-0.58	6.00	-0.63	6.00	-0.68	6.50	-0.83
6.00	-0.64	6.50	-0.68	6.50	-0.75	7.00	-0.84
6.50	-0.64	7.00	-0.71	7.00	-0.82	7.50	-0.77
7.00	-0.63	7.50	-0.71	7.50	-0.83	8.00	-0.72
7.50	-0.65	8.00	-0.71	8.00	-0.76	8.50	-0.72
8.00	-0.68	8.50	-0.74	8.50	-0.76	9.00	-0.75
8.50	-0.75	9.00	-0.77	9.00	-0.80	9.50	-0.82
9.00	-0.81	9.50	-0.84	9.50	-0.86	10.00	-0.90
9.50	-0.93	10.00	-0.93	10.00	-0.91	10.50	-0.98
10.00	-1.06	10.50	-1.07	10.50	-1.00	11.00	-1.10
10.50	-1.23	11.00	-1.25	11.00	-1.10	12.00	-1.38
11.00	-1.40	12.00	-1.60	12.00	-1.37	13.00	-1.76
12.00	-1.72	13.00	-1.90	13.00	-1.77	14.00	-1.91
13.00	-1.93	14.00	-1.99	14.00	-1.92	15.00	-1.99
14.00	-1.99	15.00	-2.02	15.00	-1.98	16.00	-2.05
15.00	-2.05	16.00	-2.08	16.00	-2.05	17.00	-2.11
16.00	-2.10	17.00	-2.14	17.00	-2.12	18.00	-2.14
17.00	-2.15	18.00	-2.16	18.00	-2.15		
18.00	-2.16						

(Continued)

(Sheet 2 of 3)



Table C11 (Concluded)

Profile T11P1850	
Range (ft)	Elev. (ft)
-4.00	0.94
-0.65	0.94
-0.65	-0.12
-0.55	-0.14
0.00	-0.24
0.50	-0.41
1.00	-0.43
1.50	-0.44
2.00	-0.45
2.50	-0.47
3.00	-0.49
3.50	-0.52
4.00	-0.53
4.50	-0.56
5.00	-0.61
5.50	-0.67
6.00	-0.72
6.50	-0.79
7.00	-0.85
7.50	-0.82
8.00	-0.77
8.50	-0.77
9.00	-0.79
9.50	-0.84
10.00	-0.90
10.50	-0.97
11.00	-1.07
12.00	-1.34
13.00	-1.68
14.00	-1.91
15.00	-1.98
16.00	-2.03
17.00	-2.08
18.00	-2.14

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Table C12

Profile Survey Data - Test T12

Profile		Profile		Profile		Profile	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
<p>This Table intentionally left blank. Profile data were recorded and plotted in Figure E18 in Appendix E.</p>							

Table C13

Profile Survey Data - Test T13

Profile		Profile		Profile		Profile	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
<p>This Table intentionally left blank. Profile data were recorded but not plotted in this report.</p>							

Table C14

Profile Survey Data, Test T14

Profile T14START		Profile T14P40		Profile T14P80		Profile T14P200	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-5.00	1.03	-7.00	1.04	-7.00	1.04	-7.00	1.04
-4.00	0.99	-5.00	1.00	-5.00	1.00	-5.00	1.00
-3.00	0.89	-3.00	0.90	-3.00	0.84	-3.00	0.90
-2.00	0.83	-1.00	0.84	-1.00	0.84	-1.00	0.84
-1.00	0.85	0.00	0.86	0.00	0.85	0.10	0.84
0.00	0.68	0.50	0.81	0.50	0.78	0.30	0.34
1.00	0.40	1.00	0.65	0.80	0.21	1.00	0.17
2.00	0.10	1.50	0.18	1.50	0.10	1.50	0.08
3.00	-0.16	2.00	0.06	2.00	0.01	2.00	-0.01
4.00	-0.41	2.50	-0.04	2.50	-0.08	2.50	-0.10
5.00	-0.61	3.00	-0.11	3.00	-0.13	3.00	-0.16
6.00	-0.83	3.50	-0.17	3.50	-0.17	3.50	-0.21
7.00	-1.07	4.00	-0.22	4.00	-0.22	4.00	-0.24
7.87	-1.35	4.50	-0.25	4.50	-0.24	4.50	-0.28
8.00	-1.60	5.00	-0.31	5.00	-0.29	5.00	-0.35
9.00	-1.82	5.50	-0.35	5.50	-0.34	5.50	-0.40
10.00	-1.97	6.00	-0.44	6.00	-0.44	6.00	-0.45
11.00	-2.10	6.50	-0.53	6.50	-0.51	6.50	-0.51
12.00	-2.18	7.00	-0.67	7.00	-0.62	7.00	-0.58
		7.50	-0.78	7.50	-0.74	7.50	-0.64
		8.00	-0.91	8.00	-0.88	8.00	-0.75
		8.50	-1.08	8.50	-1.03	8.50	-0.89
		9.00	-1.28	9.00	-1.17	9.00	-1.05
		9.50	-1.36	9.50	-1.33	9.50	-1.20
		10.00	-1.51	10.00	-1.48	10.00	-1.38
		10.50	-1.66	10.50	-1.64	10.50	-1.55
		11.00	-1.77	11.00	-1.76	11.00	-1.71
		12.00	-1.95	12.00	-1.94	12.00	-1.91
		13.00	-2.08	13.00	-2.07	13.00	-2.05
		14.80	-2.19	14.80	-2.19	14.80	-2.17
						17.00	-2.20

(Continued)

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Table C14 (Continued)

Profile T14P470		Profile T14P720		Profile T14P1200		Profile T14P1640	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-7.00	1.04	-7.00	1.04	-7.00	1.04	-7.00	1.04
-5.00	1.00	-5.00	1.00	-5.00	1.00	-5.00	1.00
-3.00	0.90	-3.00	0.90	-3.00	0.91	-3.00	0.90
-1.00	0.84	-2.00	0.84	-2.00	0.78	-2.50	0.56
-0.50	0.83	-1.00	0.82	-1.70	0.45	-2.00	0.39
-0.30	0.41	-0.80	0.35	-1.00	0.27	-1.00	0.20
0.00	0.28	0.00	0.16	0.00	0.07	0.00	0.02
0.50	0.16	0.50	0.07	0.50	-0.01	1.00	-0.11
1.00	0.07	1.00	-0.03	1.00	-0.09	1.50	-0.15
1.50	-0.02	1.50	-0.08	1.50	-0.14	2.00	-0.19
2.00	-0.10	2.00	-0.14	2.00	-0.16	2.50	-0.22
2.50	-0.15	2.50	-0.18	2.50	-0.20	3.00	-0.26
3.00	-0.20	3.00	-0.23	3.00	-0.24	3.50	-0.30
3.50	-0.24	3.50	-0.28	3.50	-0.29	4.00	-0.34
4.00	-0.29	4.00	-0.32	4.00	-0.34	4.50	-0.38
4.50	-0.33	4.50	-0.35	4.50	-0.39	5.00	-0.42
5.00	-0.38	5.00	-0.39	5.00	-0.44	5.50	-0.46
5.50	-0.44	5.50	-0.45	5.50	-0.49	6.00	-0.51
6.00	-0.50	6.00	-0.52	6.00	-0.53	6.50	-0.57
6.50	-0.53	6.50	-0.56	6.50	-0.55	7.00	-0.63
7.00	-0.55	7.00	-0.61	7.00	-0.58	7.50	-0.64
7.50	-0.60	7.50	-0.63	7.50	-0.58	8.00	-0.64
8.00	-0.65	8.00	-0.65	8.00	-0.60	8.50	-0.63
8.50	-0.77	8.50	-0.71	8.50	-0.64	9.00	-0.66
9.00	-0.88	9.00	-0.80	9.00	-0.70	9.50	-0.71
9.50	-1.03	9.50	-0.90	9.50	-0.77	10.00	-0.81
10.00	-1.22	10.00	-1.06	10.00	-0.85	10.50	-0.90
10.50	-1.46	10.50	-1.28	10.50	-1.05	11.00	-1.03
11.00	-1.62	11.00	-1.48	11.00	-1.20	12.00	-1.45
12.00	-1.88	11.50	-1.66	12.00	-1.63	13.00	-1.88
13.00	-2.03	12.00	-1.88	13.00	-1.93	14.00	-2.01
14.00	-2.12	13.00	-2.02	14.00	-2.05	14.80	-2.06
14.80	-2.14	14.00	-2.11	14.80	-2.10	17.00	-2.15
17.00	-2.18	14.80	-2.14	17.00	-2.15	18.00	-2.17
18.00	-2.19	17.00	-2.17	18.00	-2.18	19.00	-2.19
19.00	-2.19	18.00	-2.19	19.00	-2.18		
		19.00	-2.19	20.00	-2.18		

(Continued)

(Sheet 2 of 5)

Table C14 (Continued)

Profile T14P2140		Profile T14P2770		Profile T14P3420		Profile T14P3940	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-7.00	1.04	-7.00	1.04	-7.00	1.04	-7.00	1.04
-5.00	1.00	-5.00	1.00	-5.00	1.00	-5.00	1.00
-3.30	0.91	-3.30	0.89	-3.50	0.90	-3.80	0.95
-2.90	0.55	-3.10	0.51	-3.40	0.47	-3.60	0.53
-2.00	0.33	-1.00	0.06	-1.00	0.02	-2.00	0.17
-1.00	0.13	0.00	-0.08	0.00	-0.12	0.00	-0.14
0.00	-0.03	1.00	-0.20	0.50	-0.16	0.50	-0.19
1.00	-0.14	1.50	-0.23	1.00	-0.19	1.00	-0.22
1.50	-0.18	2.00	-0.25	1.50	-0.22	1.50	-0.25
2.00	0.21	2.50	-0.28	2.00	-0.25	2.00	-0.28
2.50	-0.25	3.00	-0.32	2.50	-0.29	2.50	-0.31
3.00	-0.29	3.50	-0.31	3.00	-0.33	3.00	-0.35
3.50	-0.33	4.00	-0.39	3.50	-0.37	3.50	-0.39
4.00	-0.36	4.50	-0.44	4.00	-0.40	4.00	-0.42
4.50	-0.39	5.00	-0.46	4.50	-0.42	4.50	-0.45
5.00	-0.42	5.50	-0.51	5.00	-0.45	5.00	-0.48
5.50	-0.49	6.00	-0.56	5.50	-0.49	5.50	-0.49
6.00	-0.57	6.50	-0.64	6.00	-0.53	6.00	-0.54
6.50	-0.60	7.00	-0.72	6.50	-0.58	6.50	-0.59
7.00	-0.62	7.50	-0.68	7.00	-0.65	7.00	-0.66
7.50	-0.61	8.00	-0.64	7.50	-0.70	7.50	-0.71
8.00	-0.61	8.50	-0.64	8.00	-0.72	8.00	-0.77
8.50	-0.62	9.00	-0.64	8.50	-0.65	8.50	-0.73
9.00	-0.63	9.50	-0.68	9.00	-0.67	9.00	-0.71
9.50	-0.69	10.00	-0.72	9.50	-0.68	9.50	-0.69
10.00	-0.76	10.50	-0.80	10.00	-0.70	10.00	-0.71
10.50	-0.86	11.00	-0.87	10.50	-0.77	10.50	-0.75
11.00	-0.95	12.00	-1.14	11.00	-0.85	11.00	-0.82
12.00	-1.32	13.00	-1.66	12.00	-1.04	12.00	-1.00
13.00	-1.80	14.00	-1.97	13.00	-1.50	13.00	-1.33
14.00	-1.99	14.80	-2.04	14.00	-1.91	14.00	-1.83
14.80	-2.03	17.00	-2.15	14.80	-1.95	14.80	-1.95
17.00	-2.15	18.00	-2.17	17.00	-2.10	17.00	-2.09
18.00	-2.18	19.00	-2.19	18.00	-2.16	18.00	-2.15
19.00	-2.19			19.00	-2.16	19.00	-2.16
				20.00	-2.17	20.00	-2.17
				21.00	-2.18	21.00	-2.17
				22.00	-2.18	22.00	-2.19

(Continued)

(Sheet 3 of 5)

Table C14 (Continued)

Profile T14P4590		Profile T14P5250		Profile T14P5770		Profile T14P6290	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-7.00	1.04	-7.00	1.04	-7.00	1.04	-7.00	1.04
-5.00	1.00	-5.00	1.00	-5.00	1.00	-5.00	1.00
-3.90	0.95	-4.50	0.96	-4.50	0.98	-4.50	0.95
-3.70	0.53	-4.40	0.53	-4.30	0.53	-4.40	0.53
-3.00	0.35	-3.50	0.36	-3.00	0.22	-3.00	0.20
-2.50	0.23	-3.00	0.25	-2.00	0.05	-2.00	0.03
-2.00	0.14	-2.00	0.12	-1.00	-0.12	-1.00	-0.13
-1.50	0.05	-1.00	-0.10	0.00	-0.21	0.00	-0.21
-1.00	-0.03	-0.50	-0.14	1.00	-0.27	1.00	-0.26
0.00	-0.17	0.00	-0.19	2.00	-0.33	1.50	-0.28
0.50	-0.21	0.50	-0.23	3.00	-0.37	2.00	-0.31
1.00	-0.24	1.00	-0.26	4.00	-0.45	2.50	-0.35
1.50	-0.28	1.50	-0.28	4.50	-0.50	3.00	-0.38
2.00	-0.31	2.00	-0.30	5.00	-0.55	3.50	-0.42
2.50	-0.35	2.50	-0.34	5.50	-0.55	4.00	-0.46
3.00	-0.38	3.00	-0.37	6.00	-0.55	4.50	-0.50
3.50	-0.40	3.50	-0.42	6.50	-0.60	5.00	-0.54
4.00	-0.43	4.00	-0.46	7.00	-0.65	5.50	-0.55
4.50	-0.48	4.50	-0.49	7.50	-0.69	6.00	-0.54
5.00	-0.51	5.00	-0.52	8.00	-0.78	6.50	-0.59
5.50	-0.52	5.50	-0.53	8.50	-0.85	7.00	-0.63
6.00	-0.56	6.00	-0.54	9.00	-0.86	7.50	-0.67
6.50	-0.60	6.50	-0.59	9.50	-0.78	8.00	-0.78
7.00	-0.66	7.00	-0.64	10.00	-0.73	8.50	-0.85
7.50	-0.70	7.50	-0.71	10.50	-0.72	9.00	-0.86
8.00	-0.71	8.00	-0.82	11.00	-0.78	9.50	-0.80
8.50	-0.72	8.50	-0.85	11.50	-0.82	10.00	-0.75
9.00	-0.74	9.00	-0.81	12.00	-0.90	10.50	-0.73
9.50	-0.73	9.50	-0.77	12.50	-0.98	11.00	-0.74
10.00	-0.77	10.00	-0.72	13.00	-1.07	11.50	-0.80
10.50	-0.79	10.50	-0.72	13.50	-1.26	12.00	-0.88
11.00	-0.81	11.00	-0.77	14.00	-1.55	12.50	-0.96
12.00	-0.95	11.50	-0.84	14.80	-1.87	13.00	-1.08
12.50	-1.07	12.00	-0.93	17.00	-2.06	13.50	-1.18
13.00	-1.21	12.50	-1.03	18.00	-2.14	14.00	-1.36
13.50	-1.44	13.00	-1.14	19.00	-2.18	14.80	-1.80
14.00	-1.67	13.50	-1.29	20.00	-2.18	17.00	-2.06
14.80	-1.91	14.00	-1.55	21.00	-2.18	18.00	-2.12
17.00	-2.09	14.80	-1.92	22.00	-2.19	19.00	-2.18
18.00	-2.14	17.00	-2.06			20.00	-2.18
						21.00	-2.18

(Continued)

(Sheet 4 of 5)

Table C14 (Concluded)

Profile T14P6810		Profile T14P6810	
Range (ft)	Elev. (ft)	Range (ft)	Elev. (ft)
-7.00	1.04	6.50	-0.57
-5.00	0.99	7.00	-0.61
-4.60	0.56	7.50	-0.67
-4.00	0.41	8.00	-0.73
-3.50	0.30	8.50	-0.83
-3.00	0.19	9.00	-0.87
-2.50	0.09	9.50	-0.85
-2.00	0.01	10.00	-0.77
-1.50	-0.08	10.50	-0.72
-1.00	-0.13	11.00	-0.74
-0.50	-0.16	11.50	-0.78
0.00	-0.19	12.00	-0.84
0.50	-0.22	13.00	-1.02
1.00	-0.26	13.50	-1.14
1.50	-0.28	14.00	-1.31
2.00	-0.32	14.80	-1.62
2.50	-0.35	17.00	-2.04
3.00	-0.38	18.00	-2.11
3.50	-0.41	19.00	-2.17
4.00	-0.44	20.00	-2.17
4.50	-0.49	22.00	-2.18
5.00	-0.53	24.00	-2.18
5.50	-0.54	26.00	-2.18
6.00	-0.54	27.00	-2.18

(Sheet 5 of 5)



## APPENDIX D: PLOTS OF EXPERIMENT PROFILES

1. The plots shown in this appendix are results from the movable-bed physical model plotted in model units. The solid profile line represents the profile recorded after the specified number of waves, whereas the dashed profile line marks the position of the previously recorded profile. All profiles are center-line profiles except those denoted with an uppercase G (glass sidewall) or an uppercase C (concrete sidewall). Profiles of T12 and T13 have been purposely omitted from this appendix.

Test	Description of Test	Figure Number
T01	Reproduction of prototype experiment using 10-m horizontal width berm	Figure D1
T02	Repeat of T01 to demonstrate repeatability	Figure D2
T03	Reproduction of prototype experiment using 11-m horizontal width berm (same as prototype)	Figure D3
T04	Repeat of T03 with wave height increased by 10 percent to examine impact of height variations	Figure D4
T05	Repeat of T03 using absorbing wave paddle	Figure D5
T06	Repeat of T03 starting with the prototype profile at 40 waves molded in the flume to examine effect of initial profile on evolution.	Figure D6
T07	Repeat of T03 with wave period decreased 10 percent to examine impact of period variations	Figure D7
T08	Repeat of T03 using irregular waves having $H_{1/3}$ equal to 141 percent of monochromatic wave height	Figure D8
T09	Repeat of T03 using irregular waves having $H_{1/3}$ equal to the monochromatic wave height	Figure D9
T10	Repeat of T03 using regular waves with a vertical seawall at the intersection of the revetment and SWL	Figure D10
T11	Repeat of T10 using irregular waves with $H_{1/3}$ equal to the monochromatic wave height	Figure D11
T14	Reproduction of prototype irregular wave test	Figure D12

## TEST T01

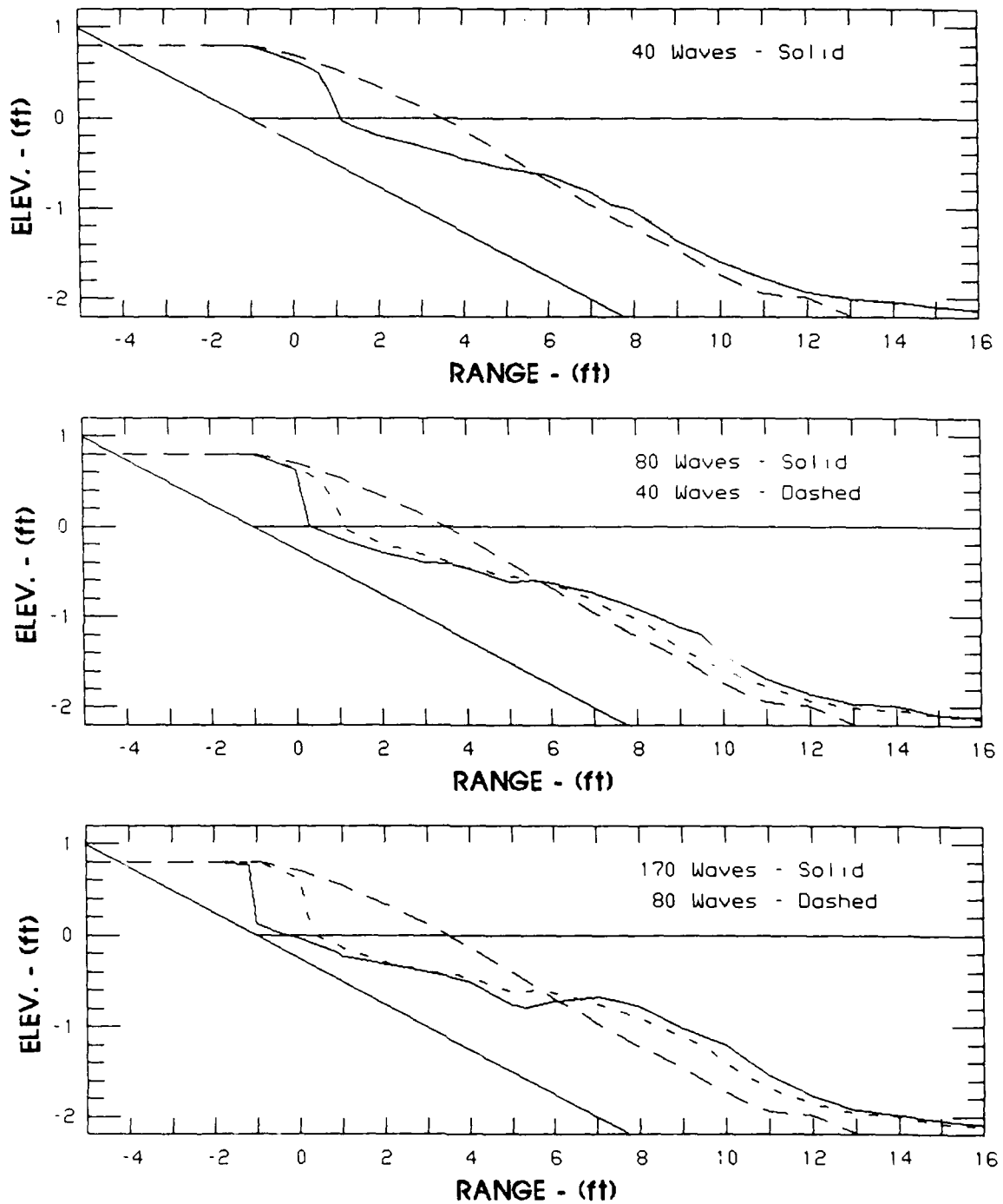


Figure D1. Test T01 profile development (Sheet 1 of 4)

# TEST T01

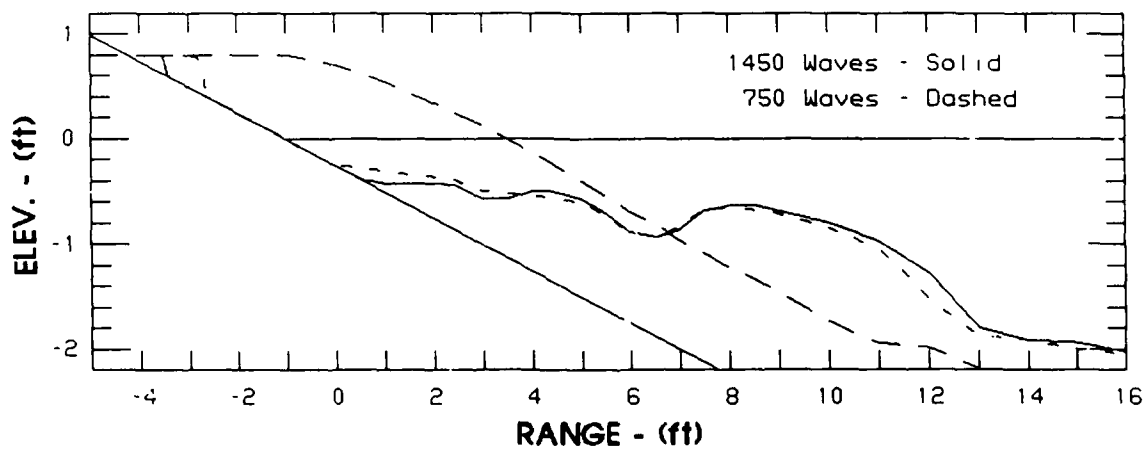
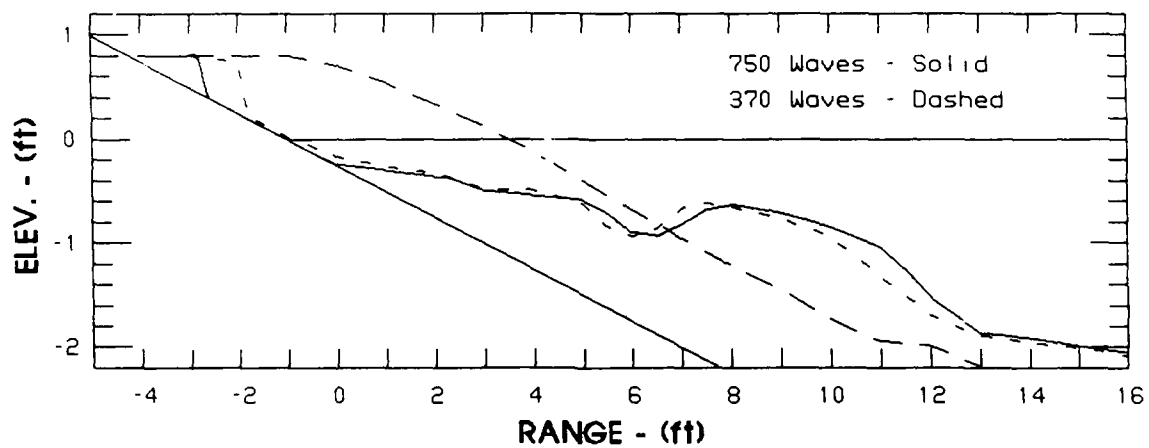
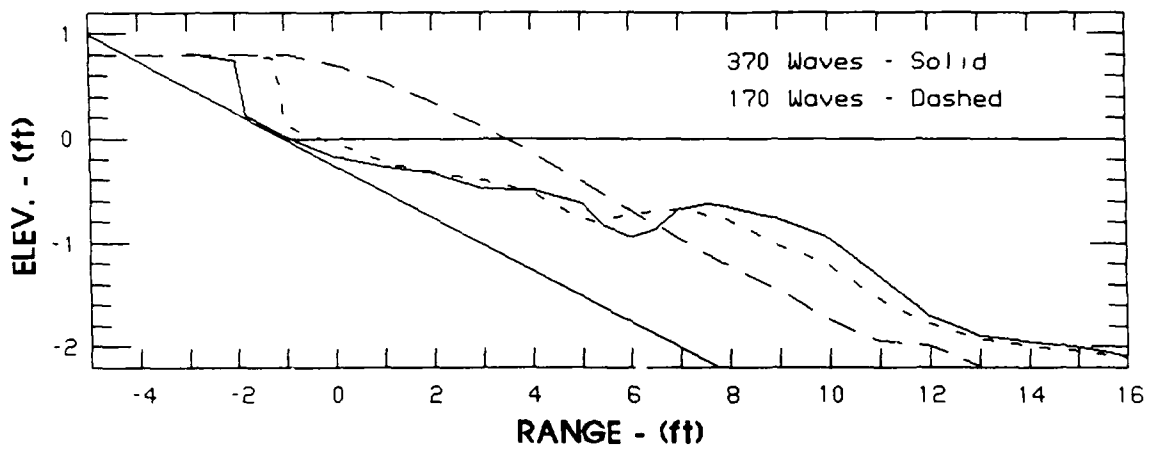


Figure D1. (Sheet 2 of 4)

# TEST T01

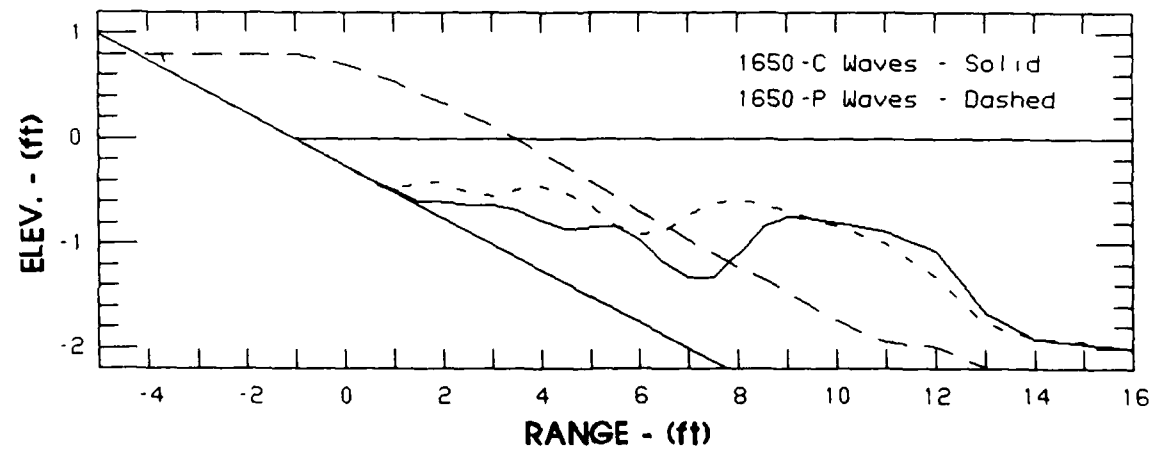
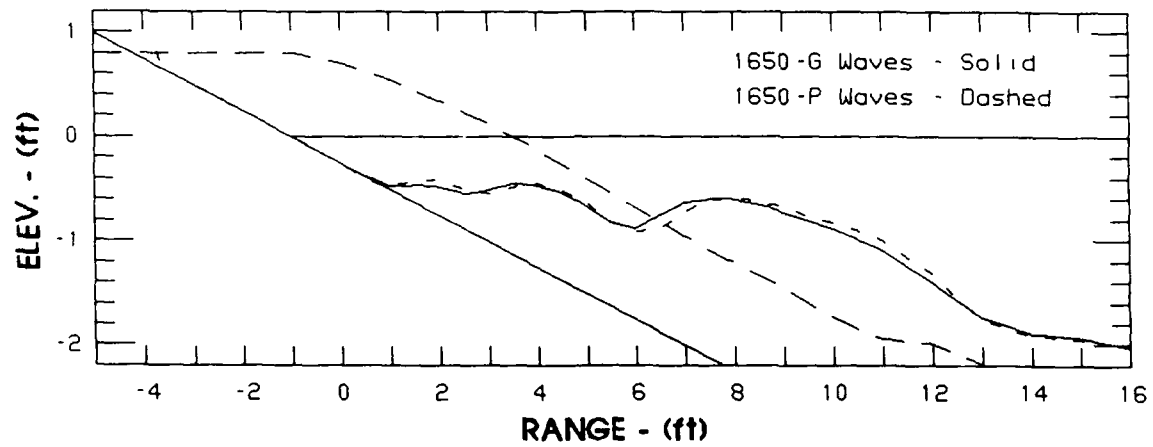
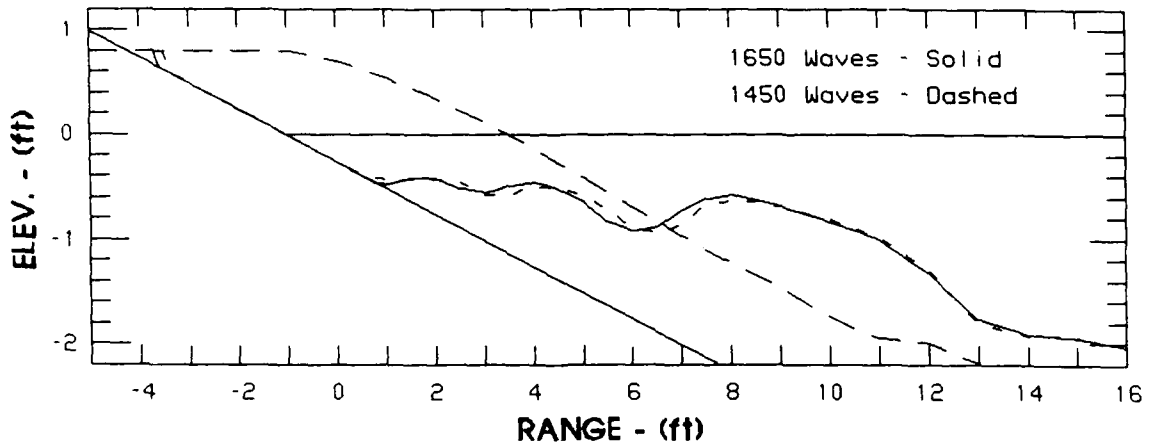


Figure D1. (Sheet 3 of 4)

## TEST T01

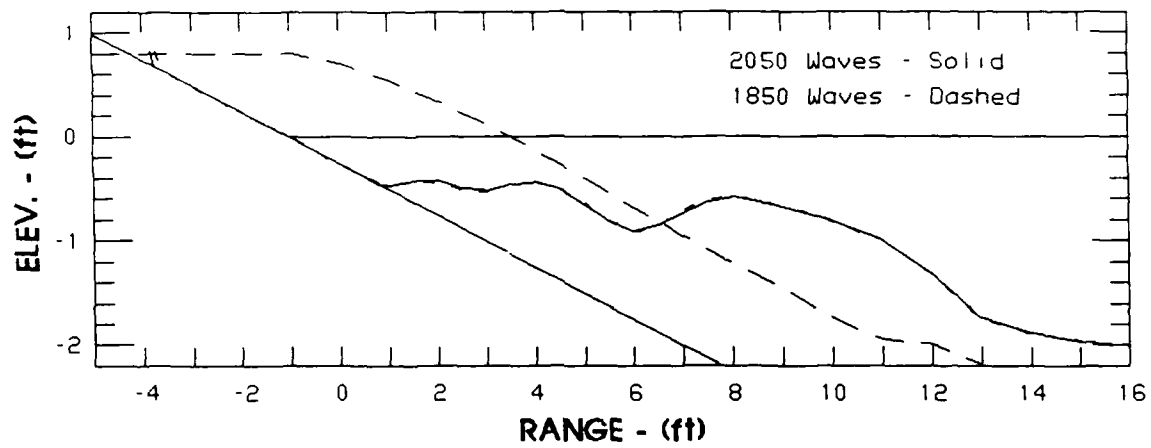
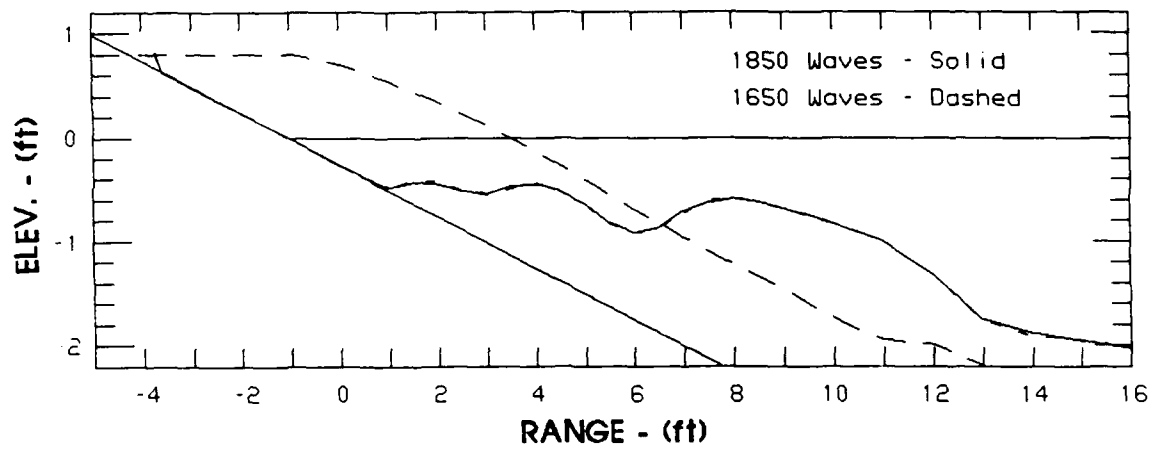


Figure D1. (Sheet 4 of 4)

## TEST T02

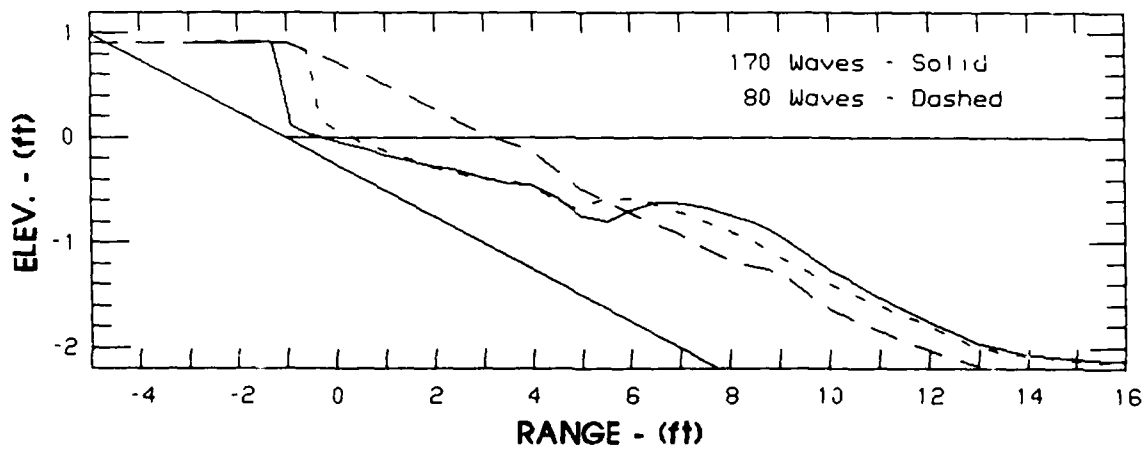
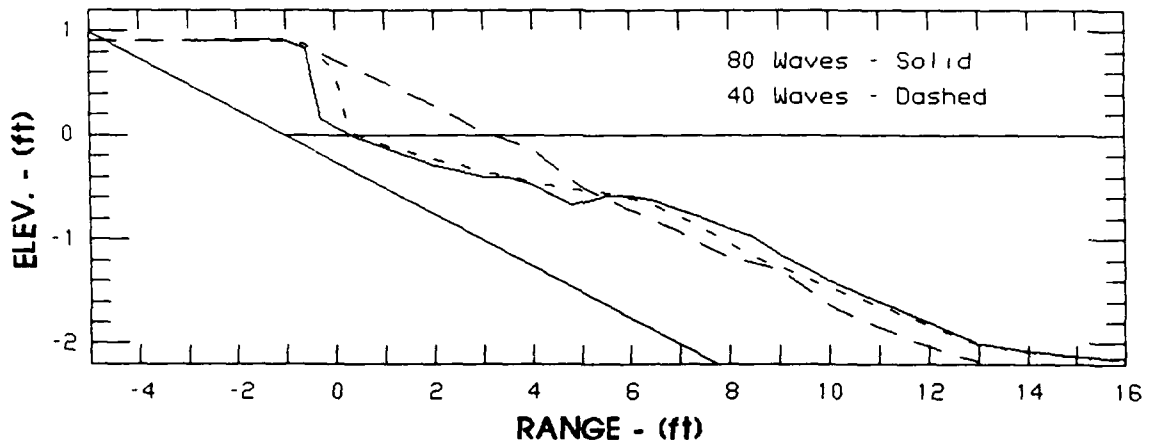
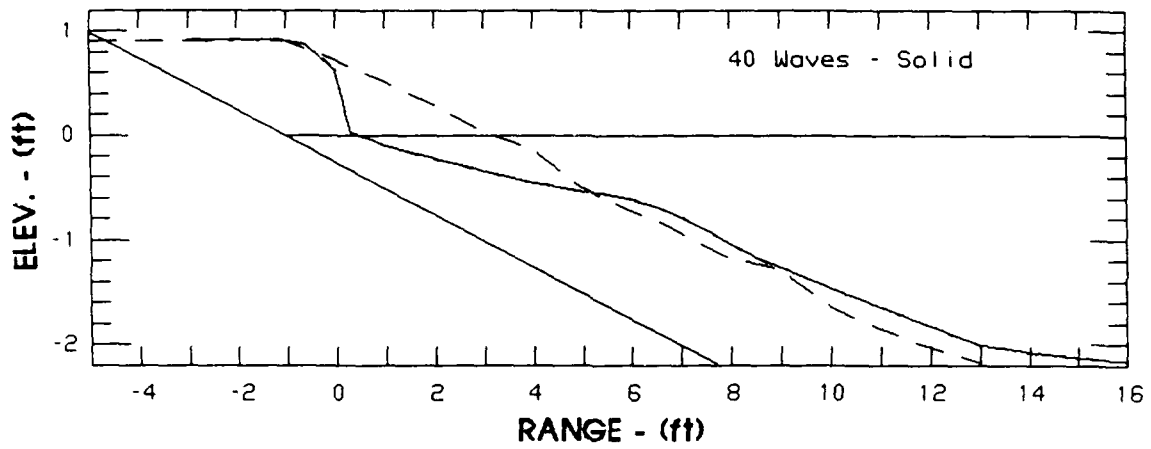


Figure D2. Test T02 profile development (Sheet 1 of 3)

## TEST T02

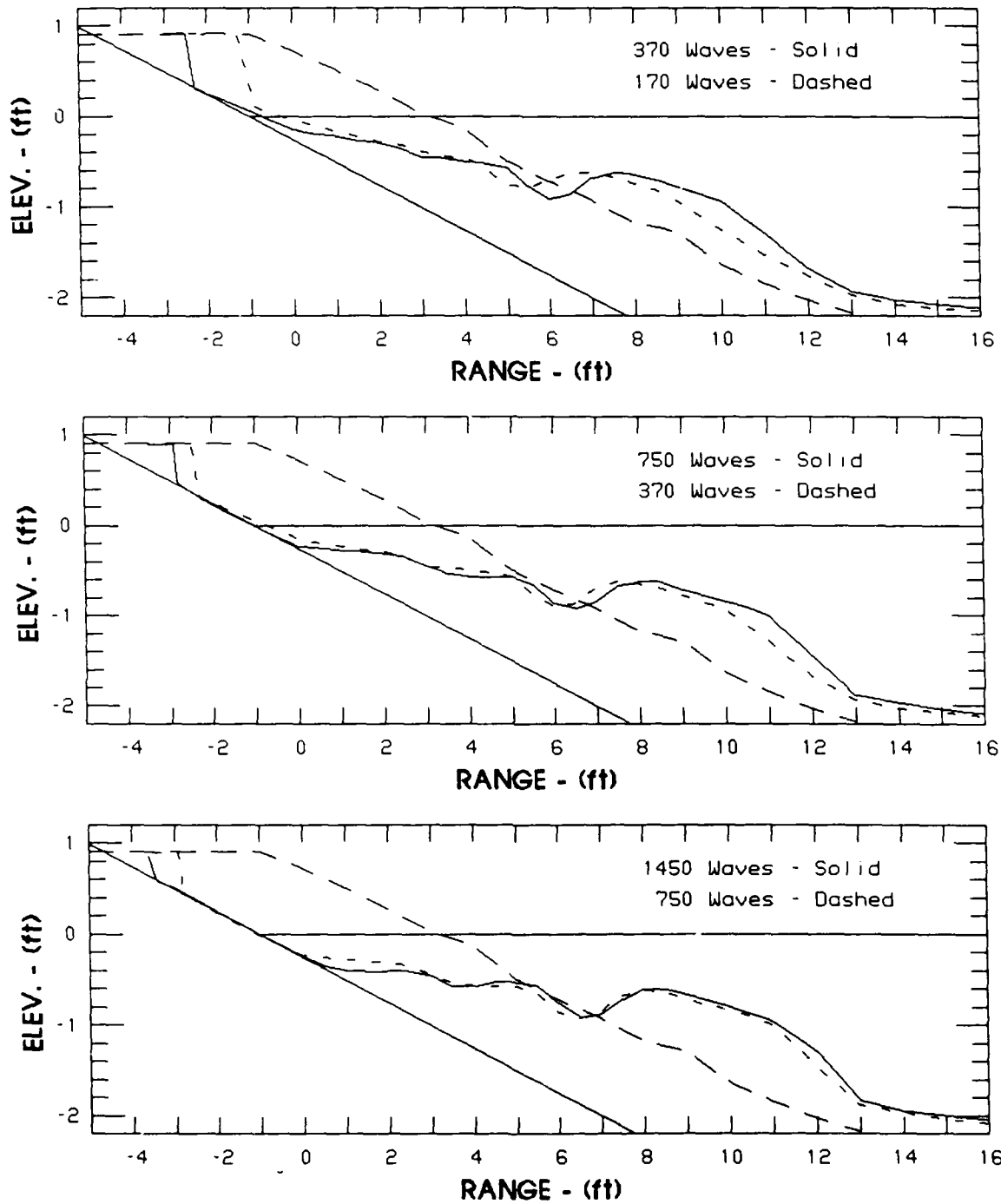


Figure D2. (Sheet 2 of 3)

## TEST T02

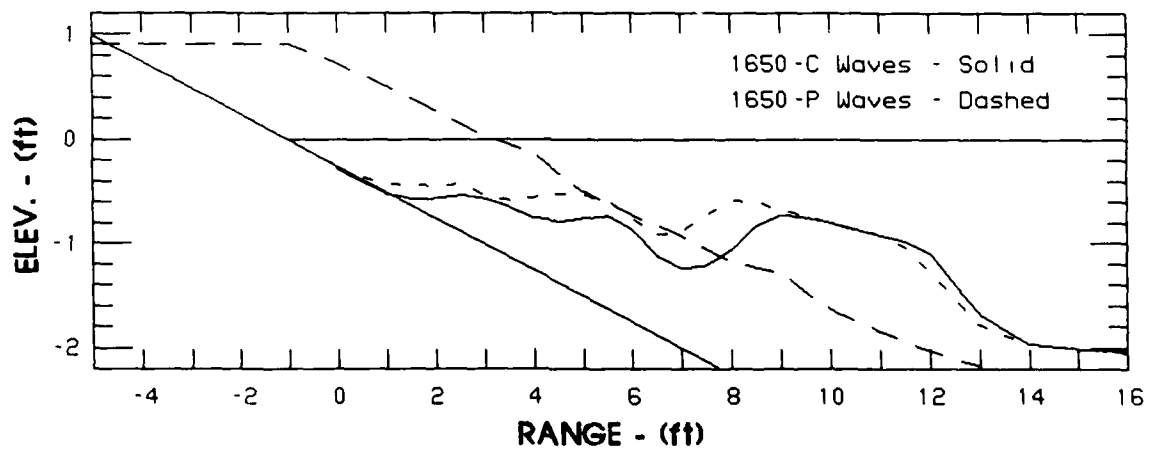
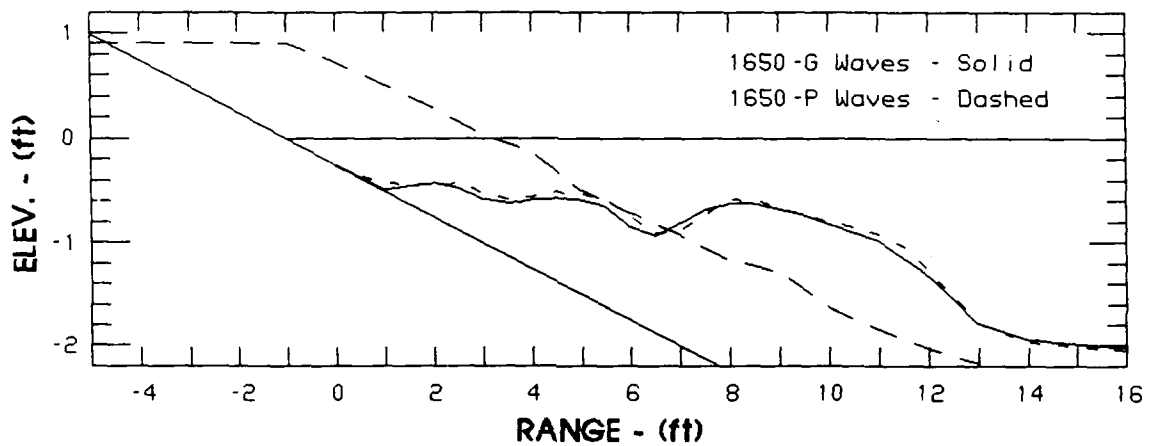
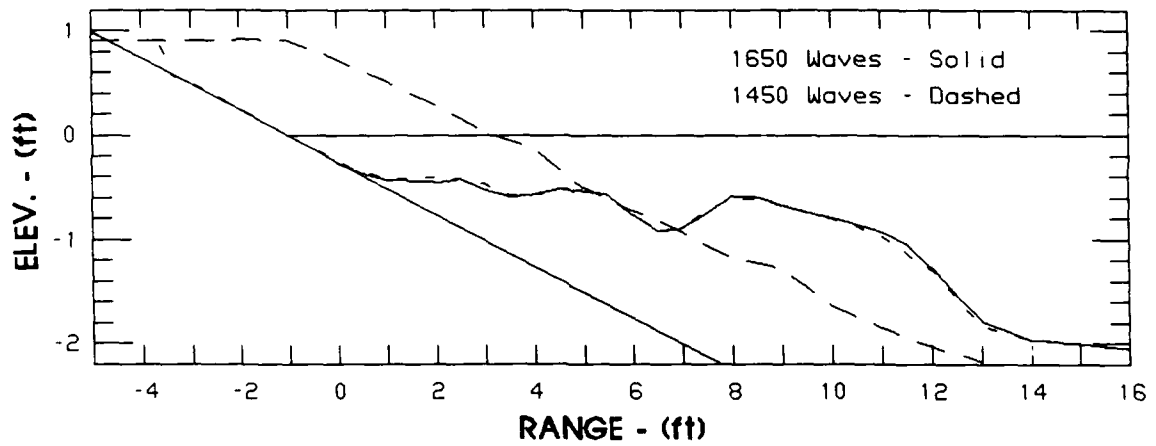


Figure D2. (Sheet 3 of 3)



## TEST T03

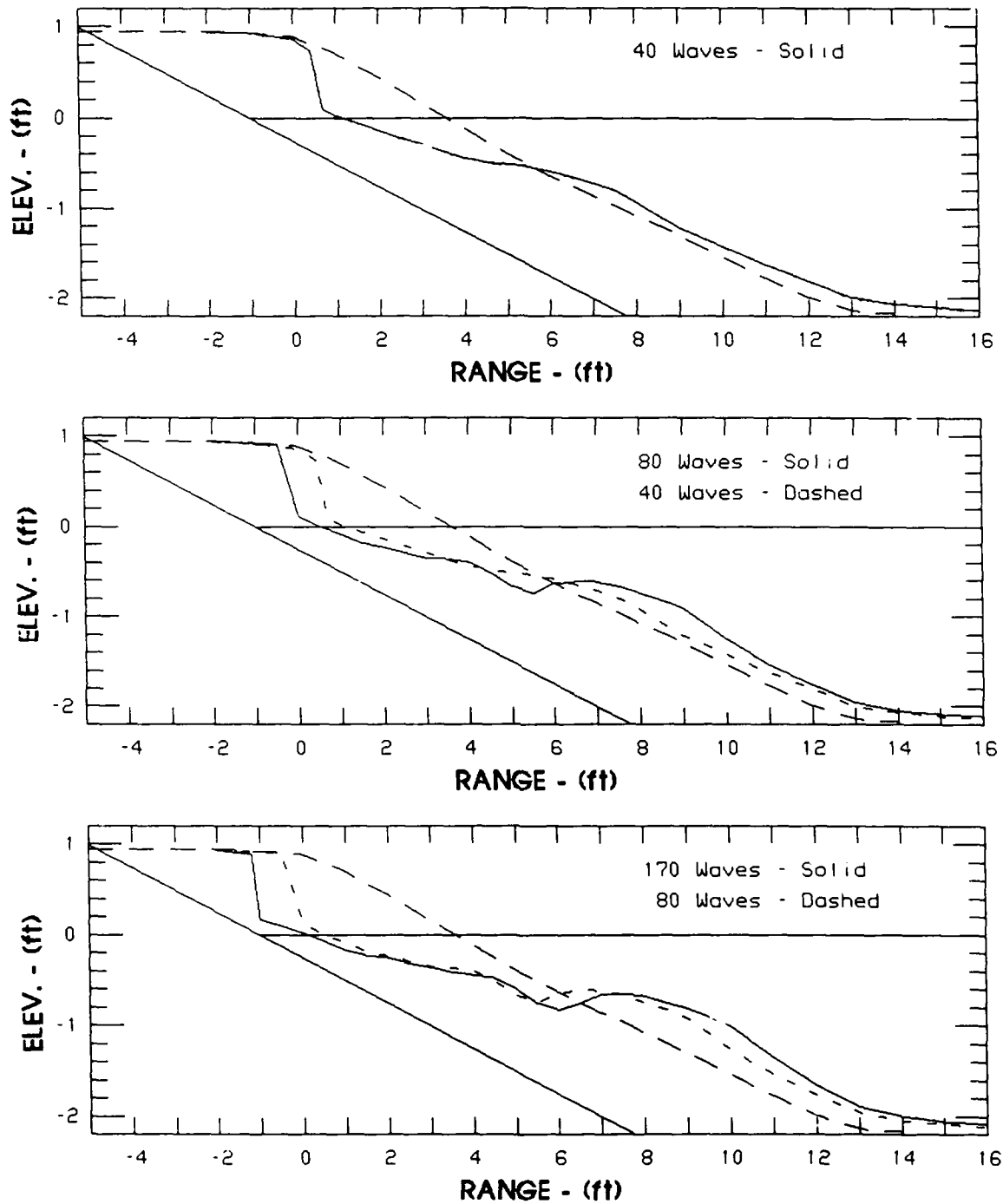


Figure D3. Test T03 profile development (Sheet 1 of 4)

# TEST T03

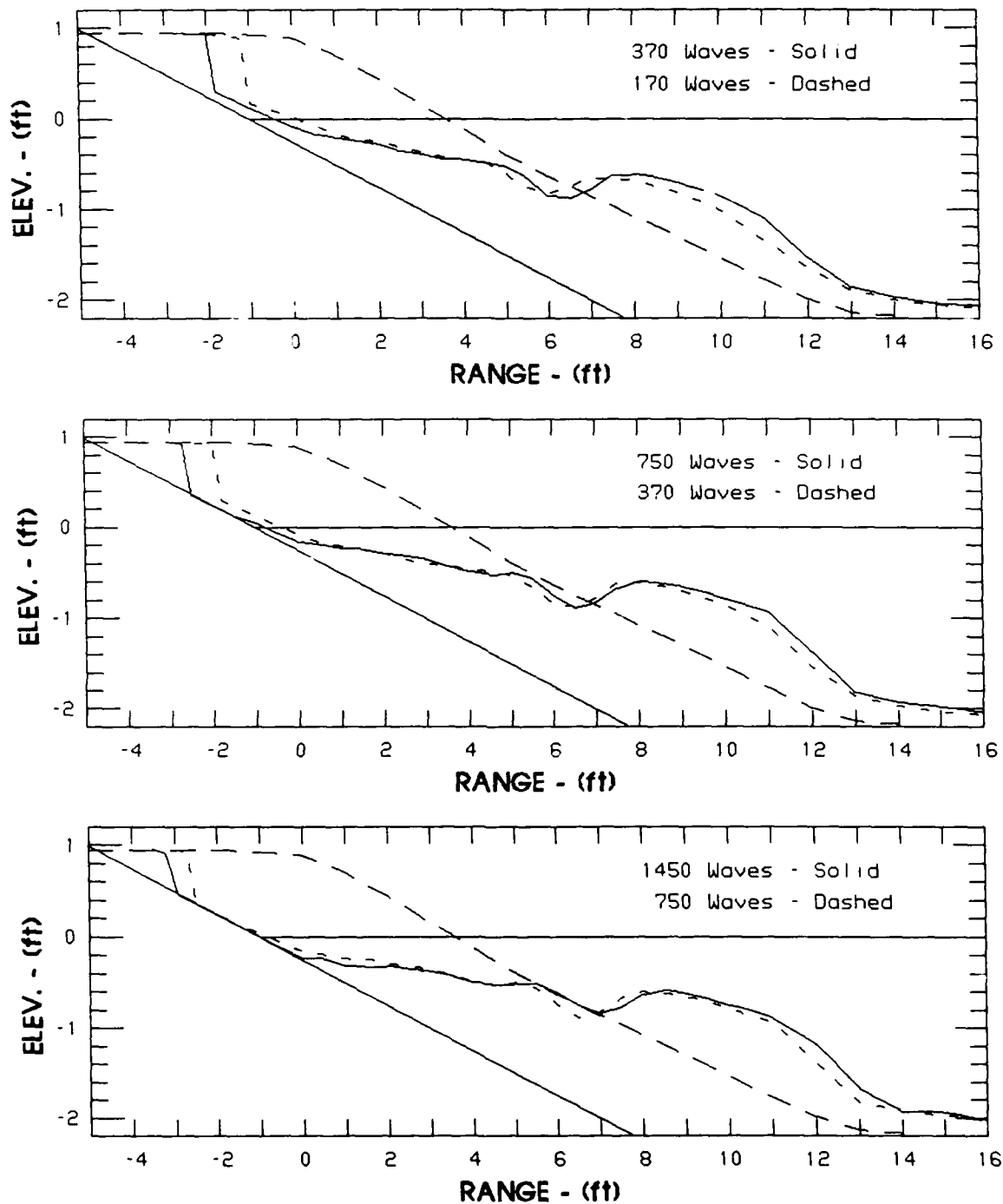


Figure D3. (Sheet 2 of 4)

# TEST T03

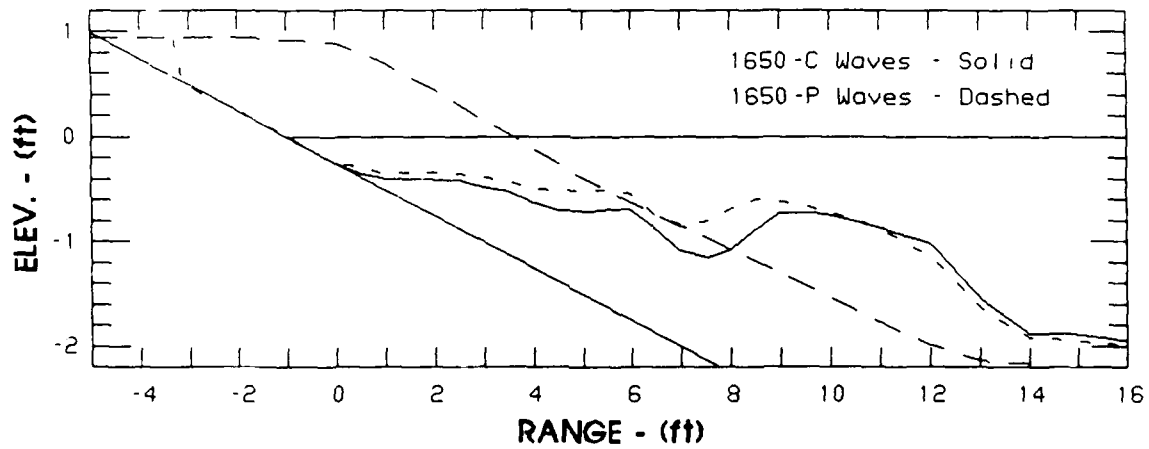
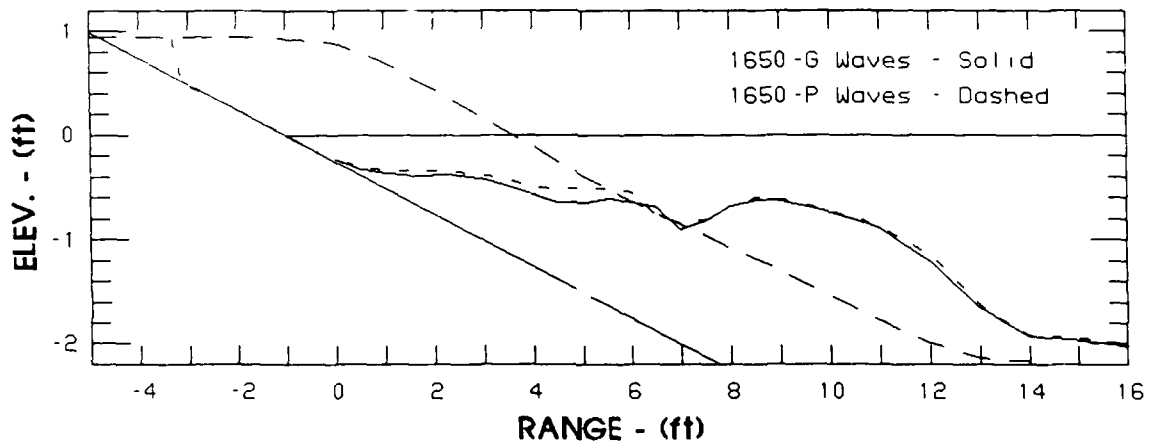
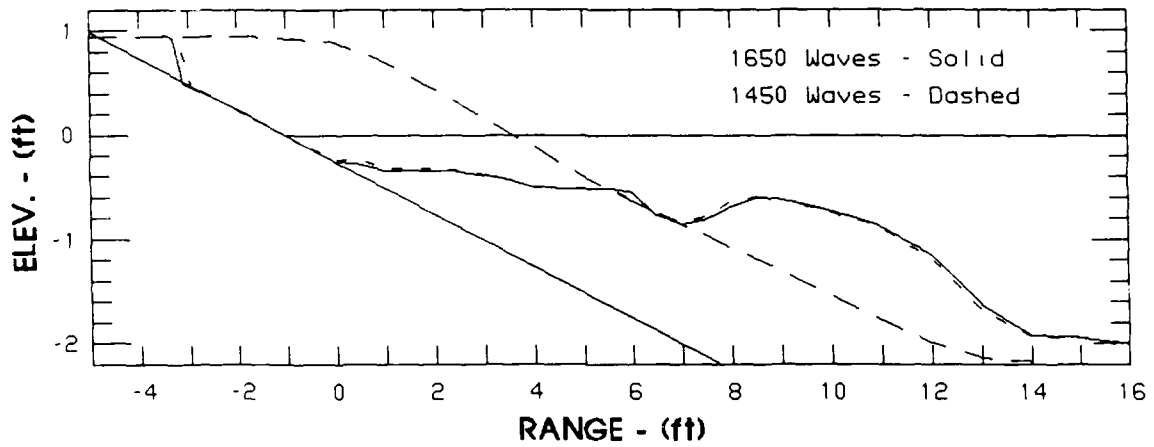


Figure D3. (Sheet 3 of 4)

## TEST T03

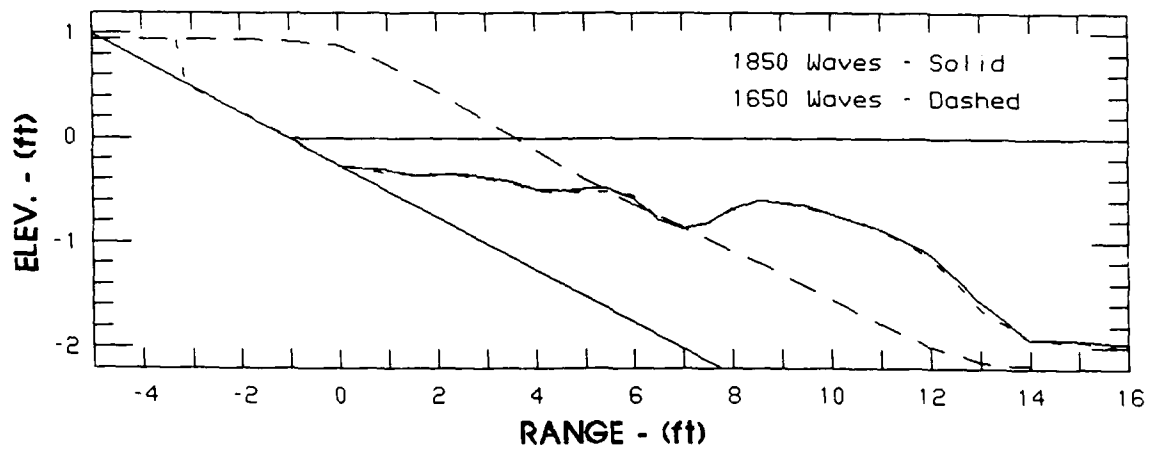


Figure D3. (Sheet 4 of 4)

## TEST T04

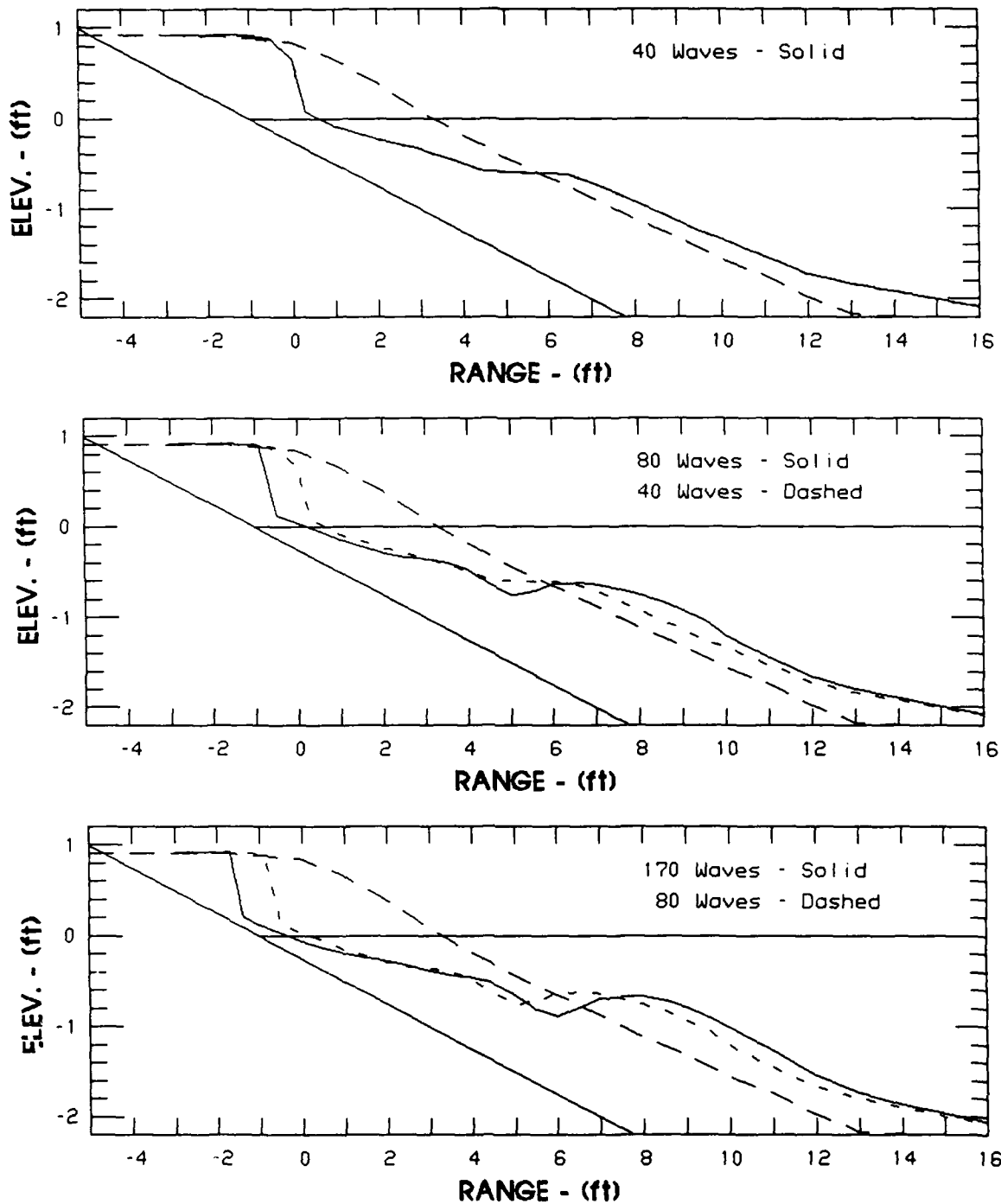


Figure D4. Test T04 profile development (Sheet 1 of 4)

# TEST T04

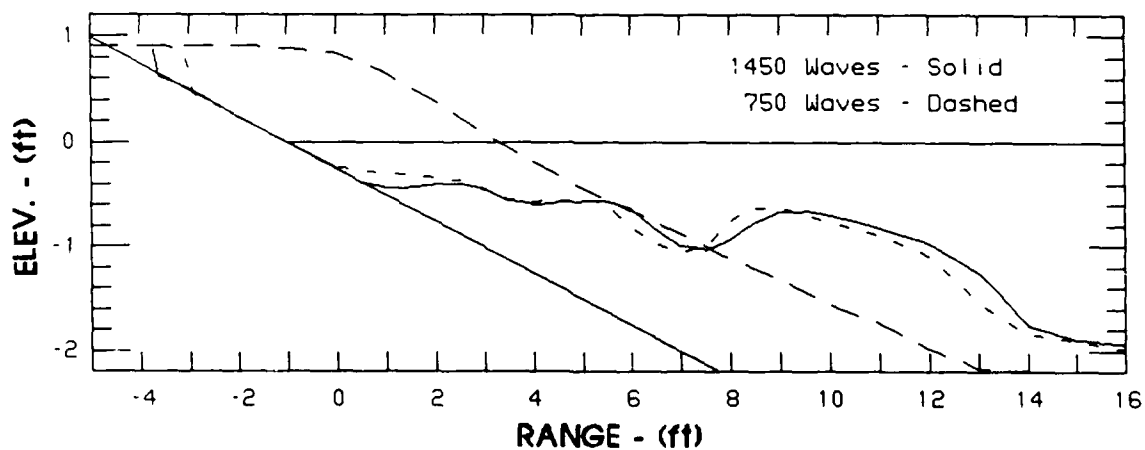
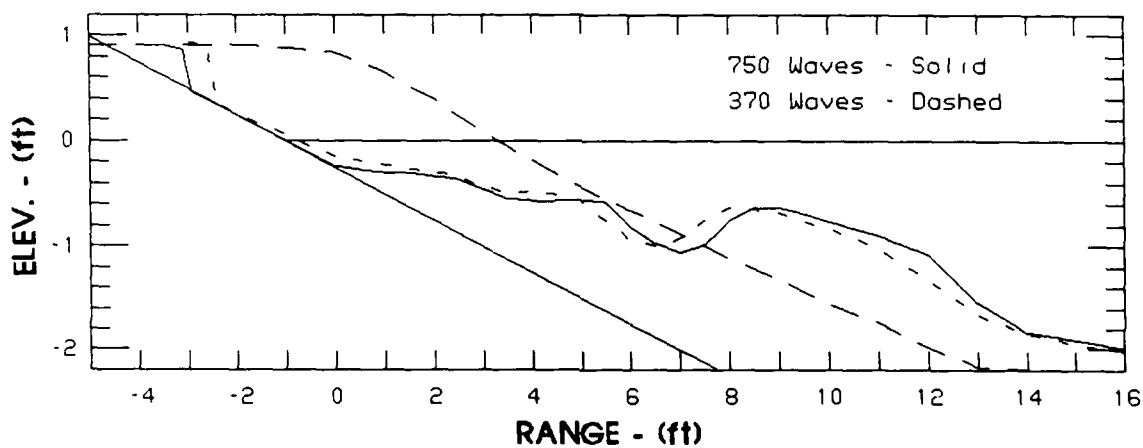
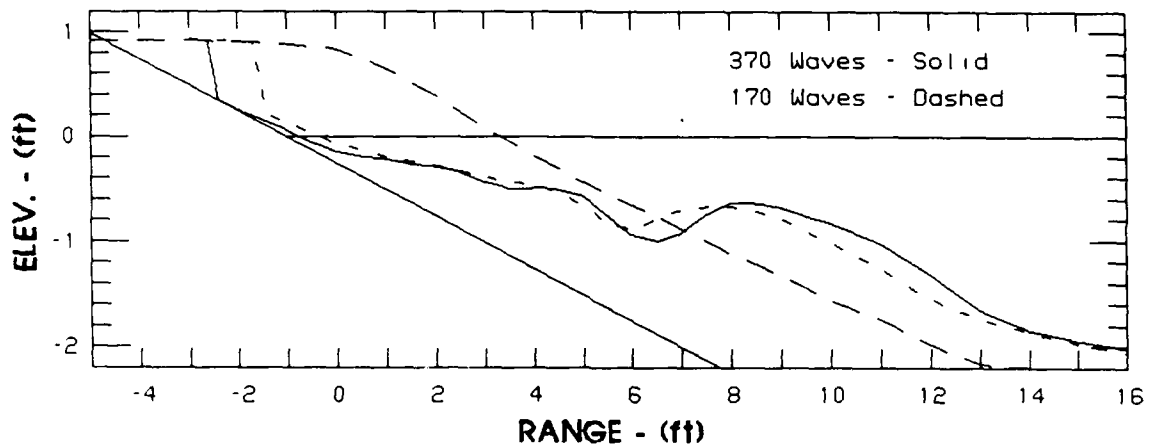


Figure D4. (Sheet 2 of 4)

# TEST T04

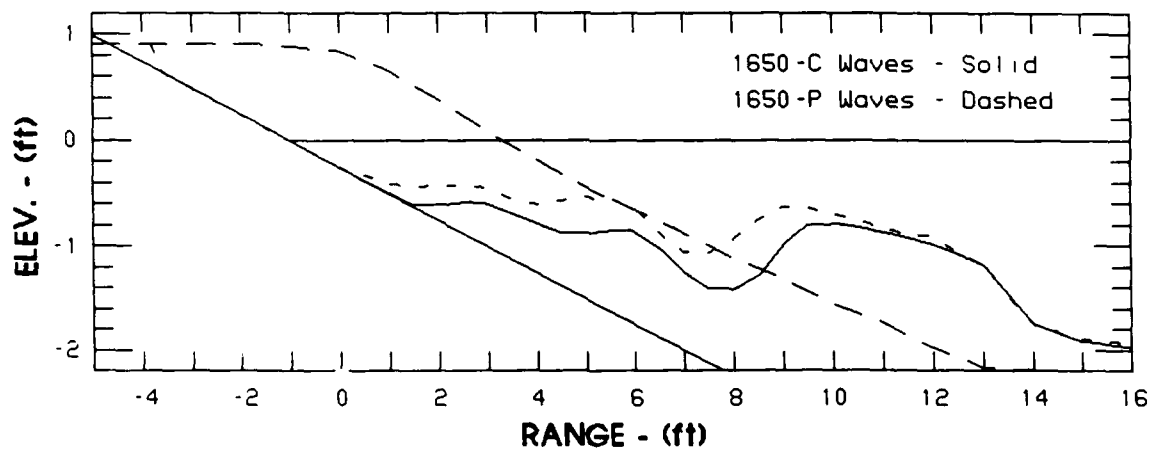
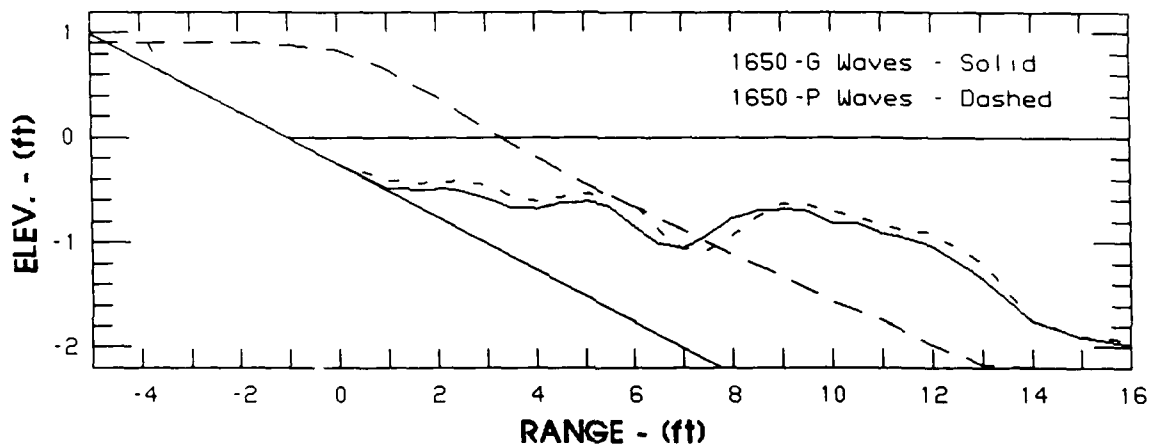
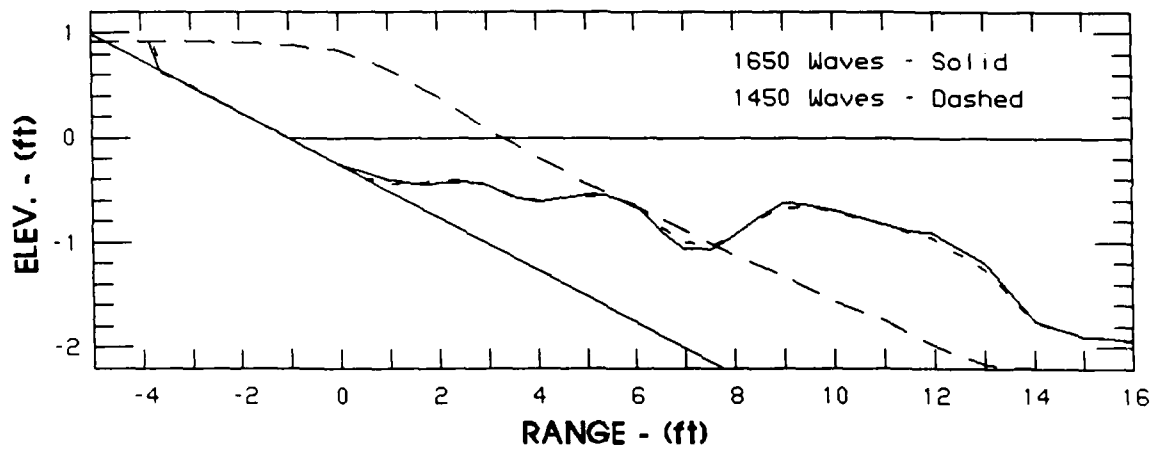


Figure D4. (Sheet 3 of 4)

## TEST T04

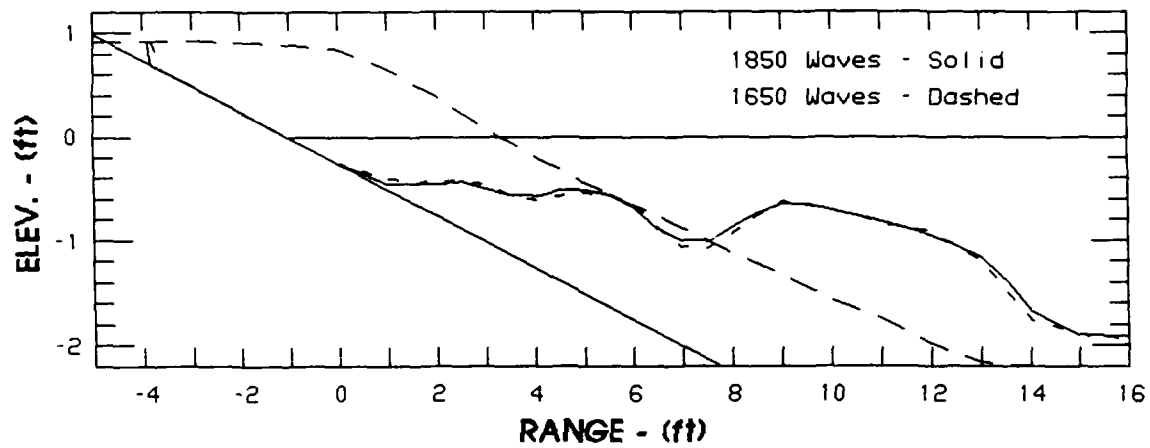


Figure D4. (Sheet 4 of 4)



## TEST T05

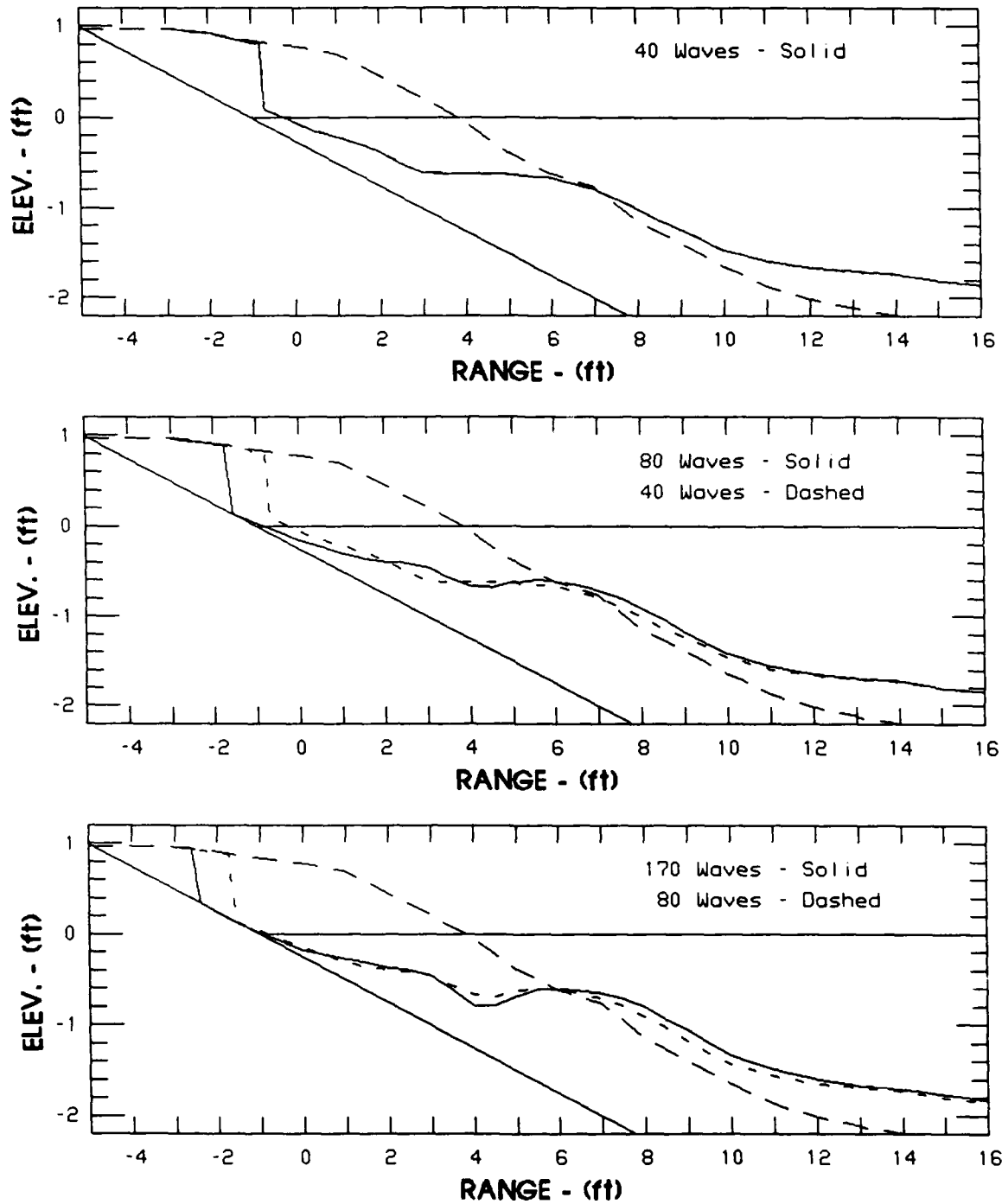


Figure D5. Test T05 profile development (Sheet 1 of 3)

## TEST T05

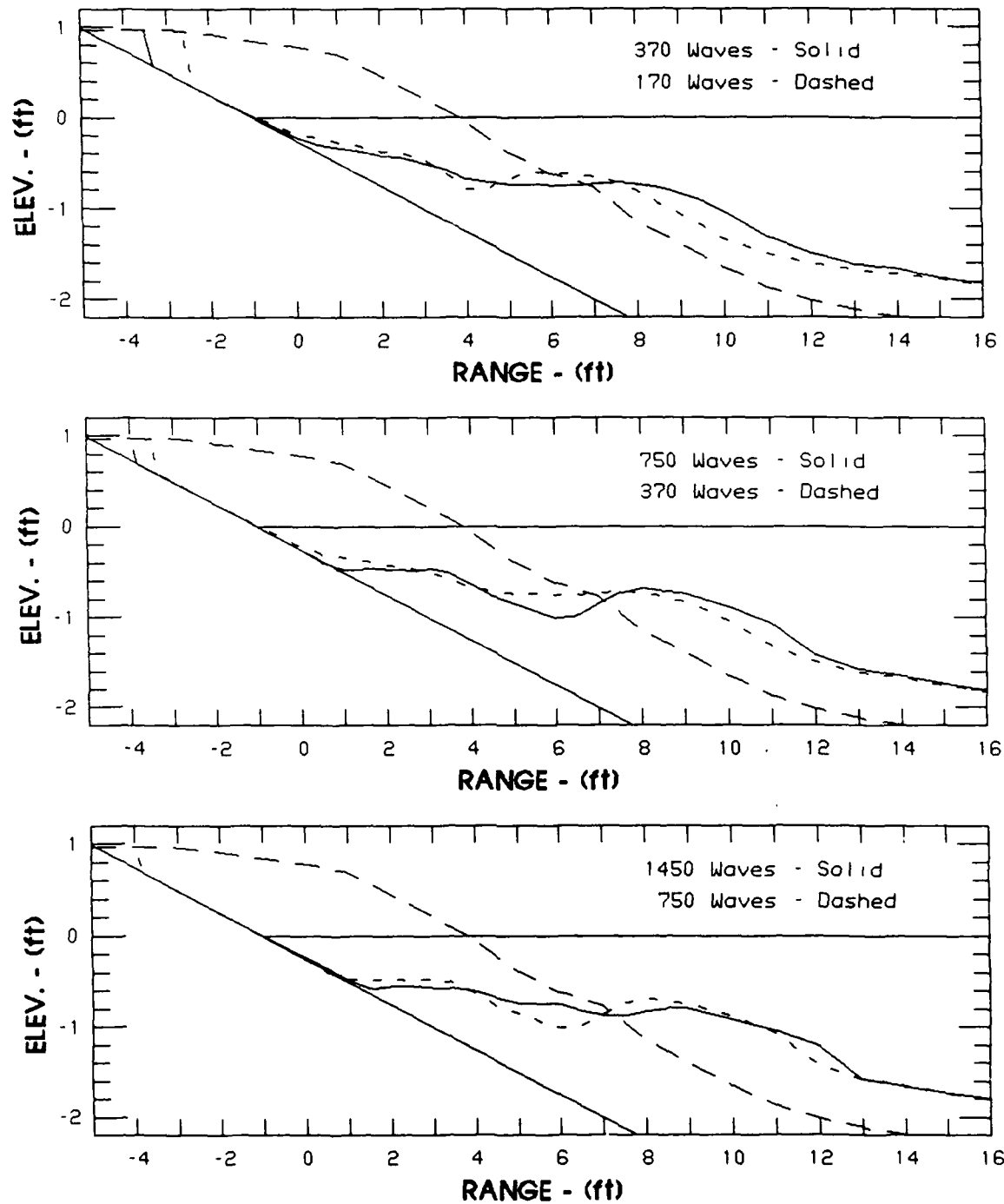


Figure D5. (Sheet 2 of 3)

## TEST T05

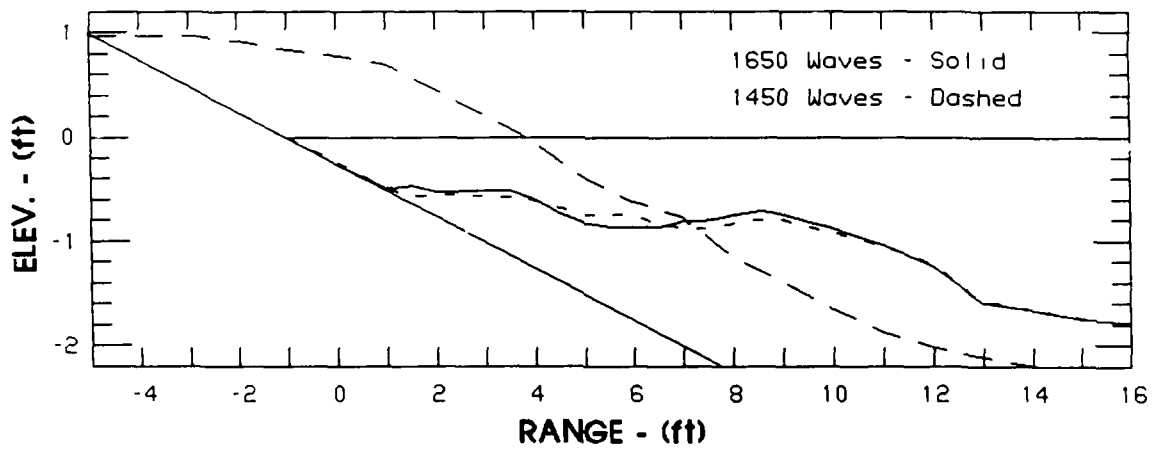


Figure D5. (Sheet 3 of 3)

## TEST T06

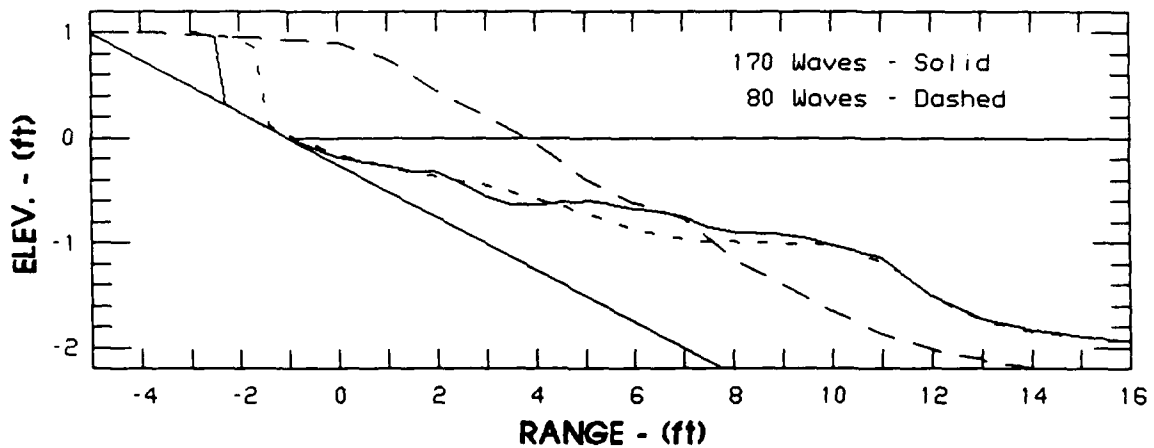
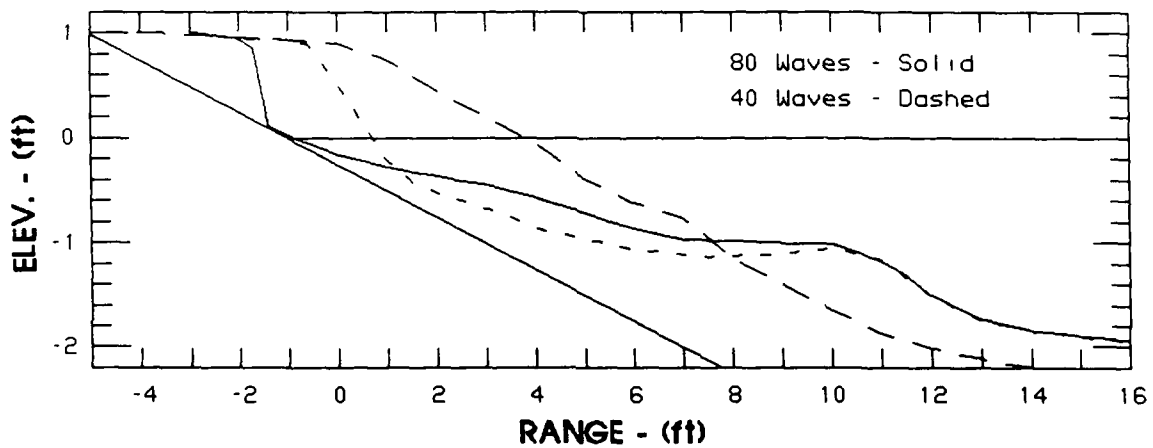
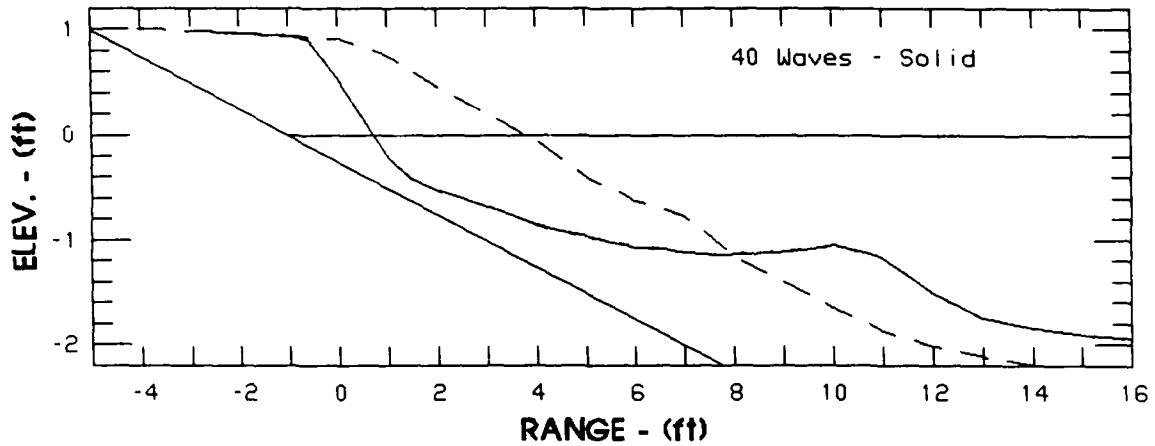


Figure D6. Test T06 profile development (Sheet 1 of 4)

## TEST T06

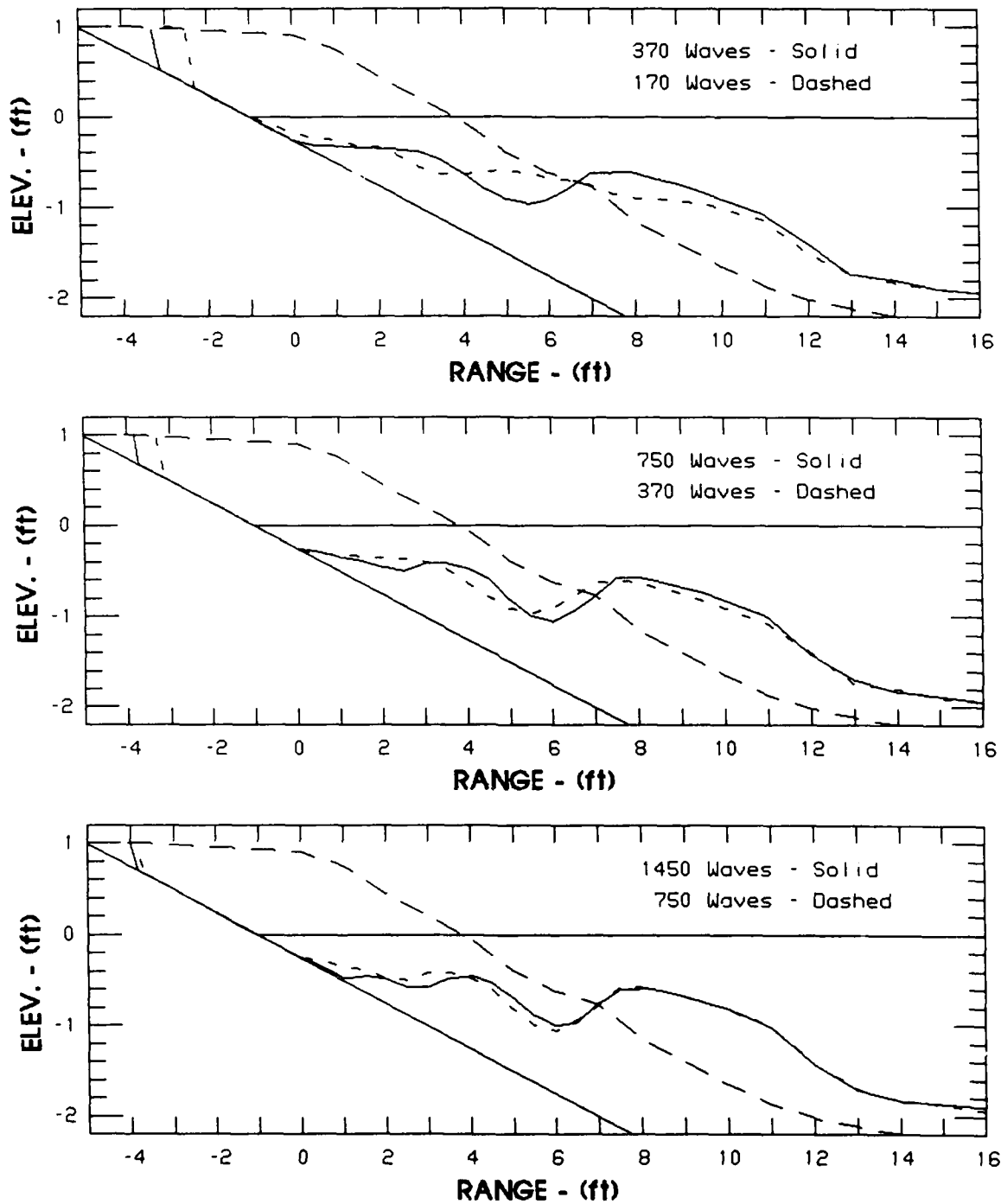


Figure D6. (Sheet 2 of 4)

## TEST T06

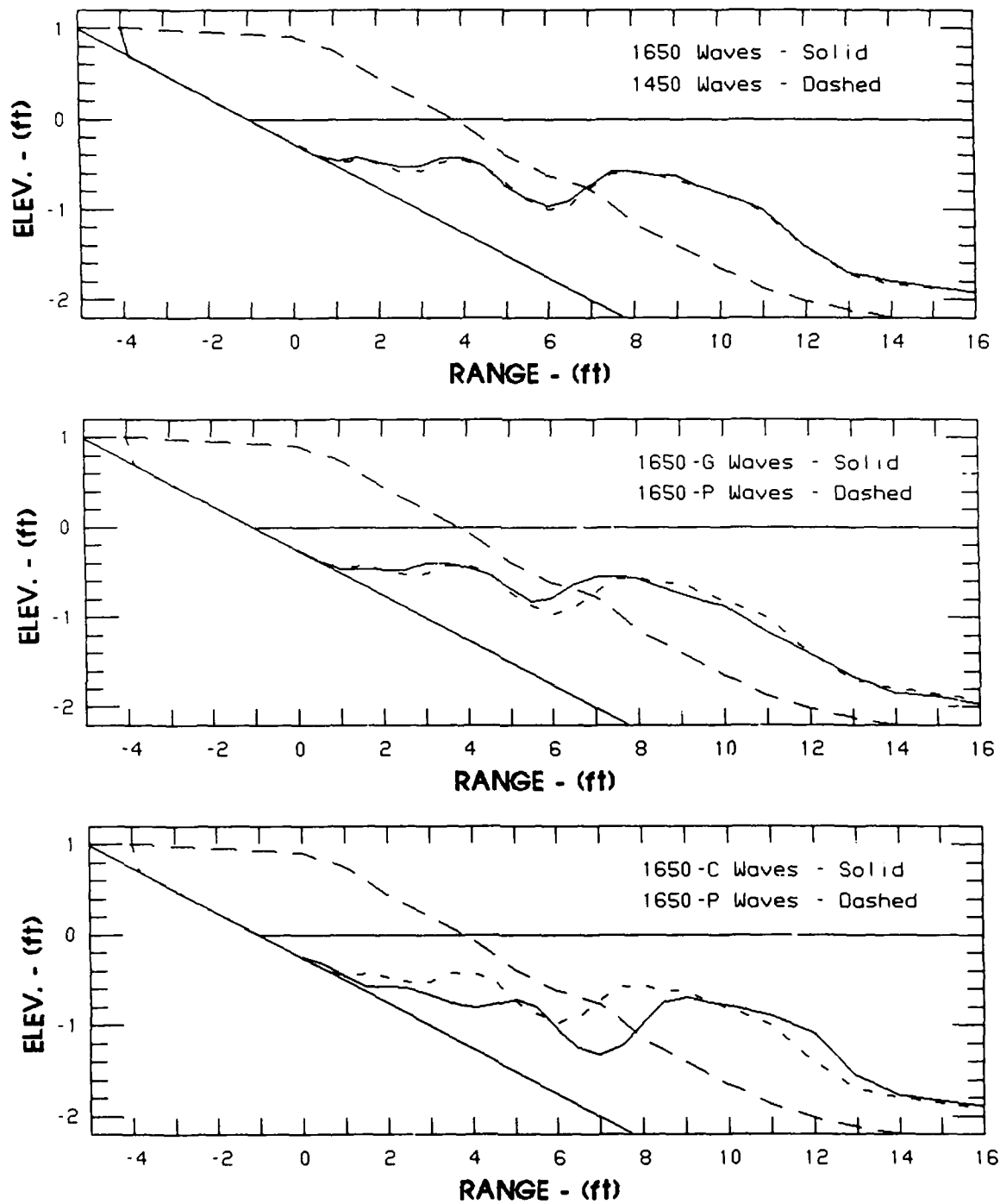


Figure D6. (Sheet 3 of 4)

## TEST T06

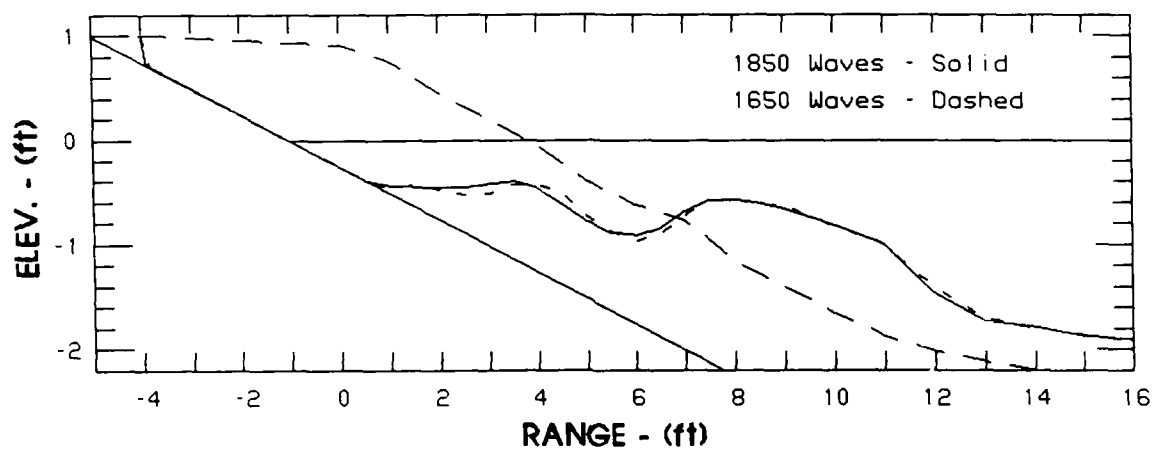


Figure D6. (Sheet 4 of 4)

## TEST T07

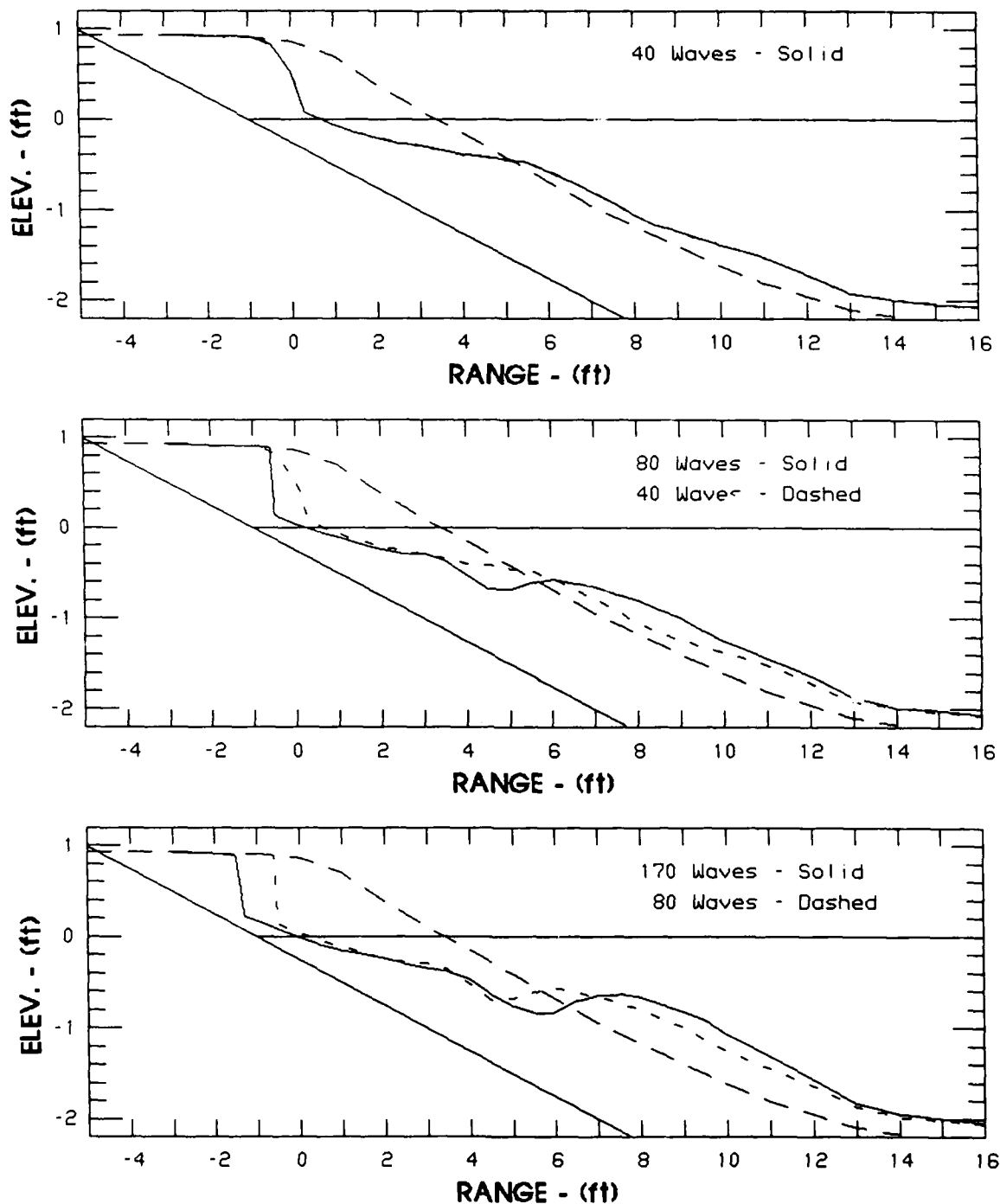


Figure D7. Test T07 profile development (Sheet 1 of 3)



# TEST T07

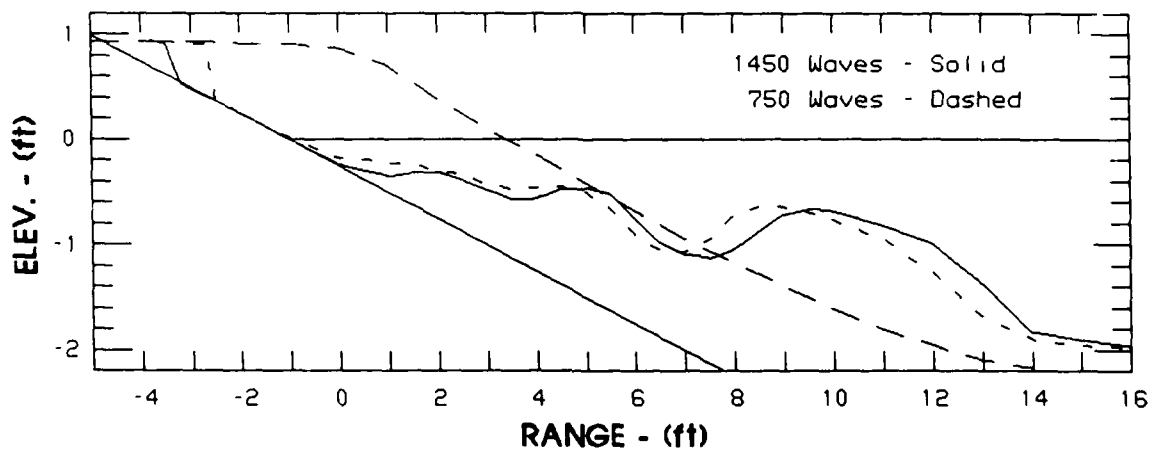
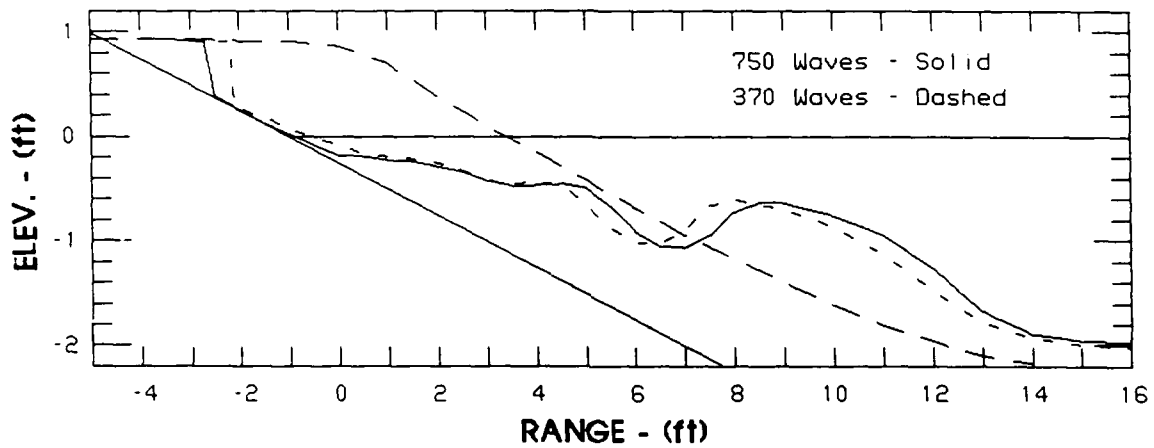
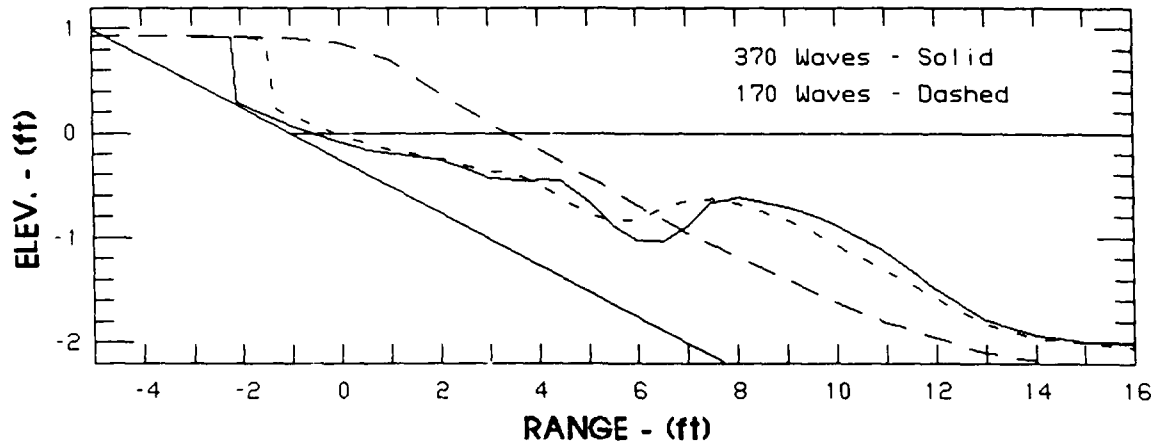


Figure D7. (Sheet 2 of 3)

## TEST T07

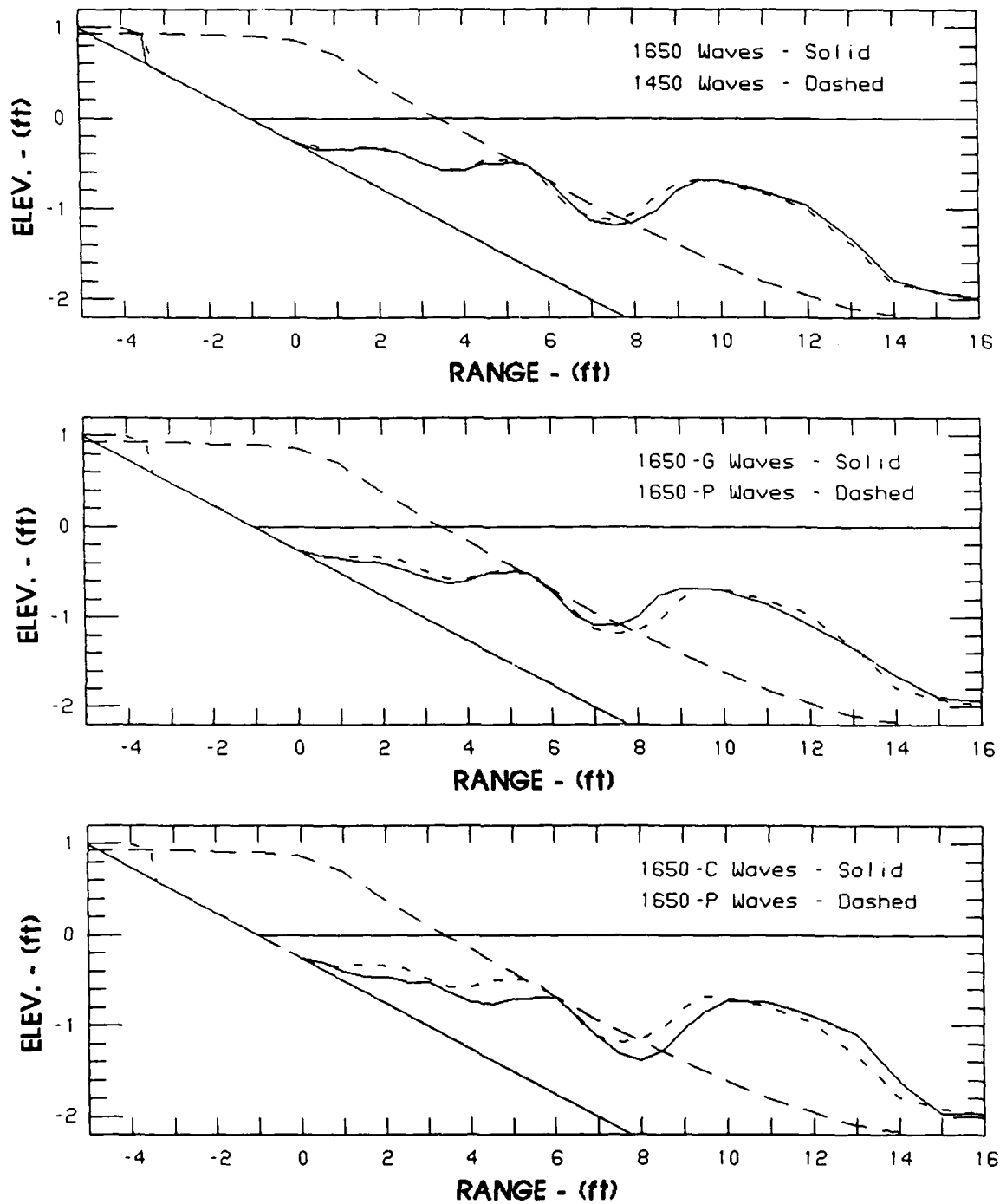


Figure D7. (Sheet 3 of 3)

## TEST T08

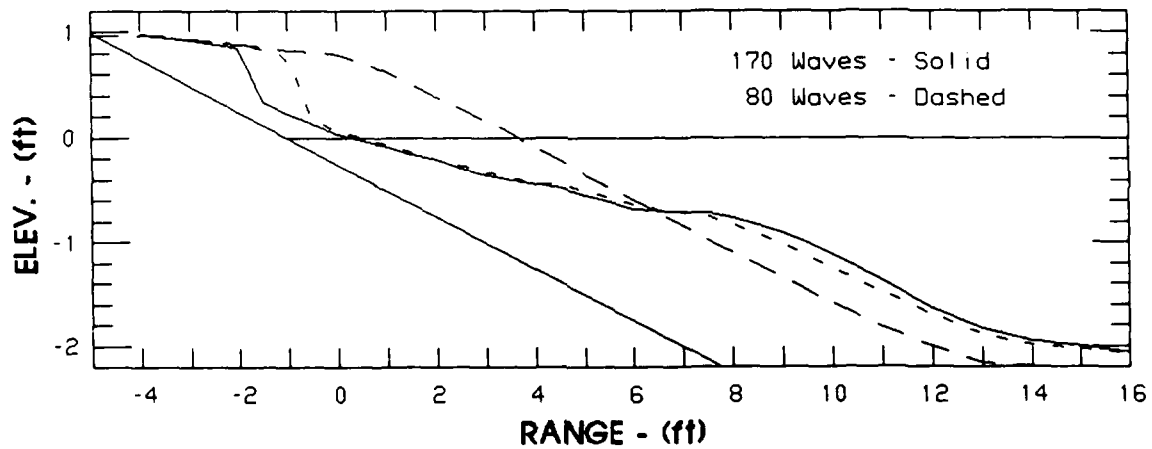
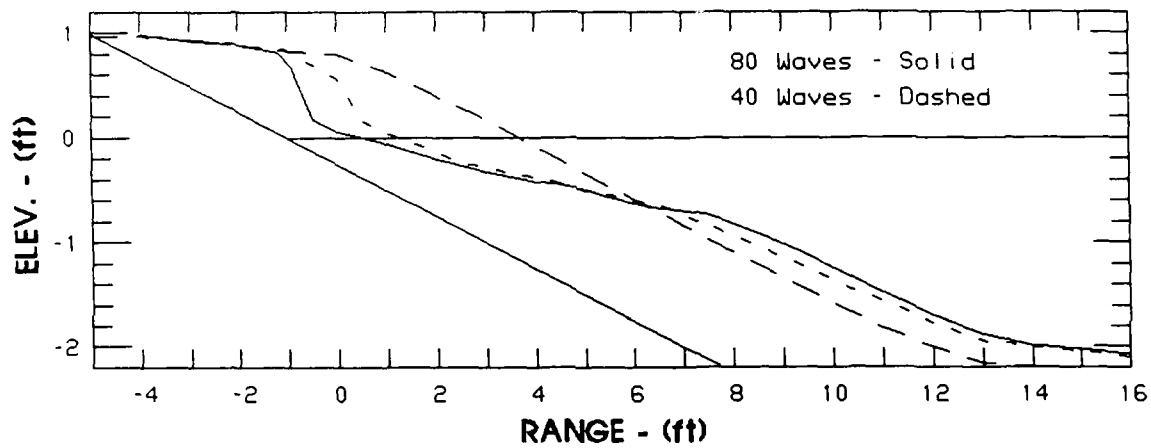
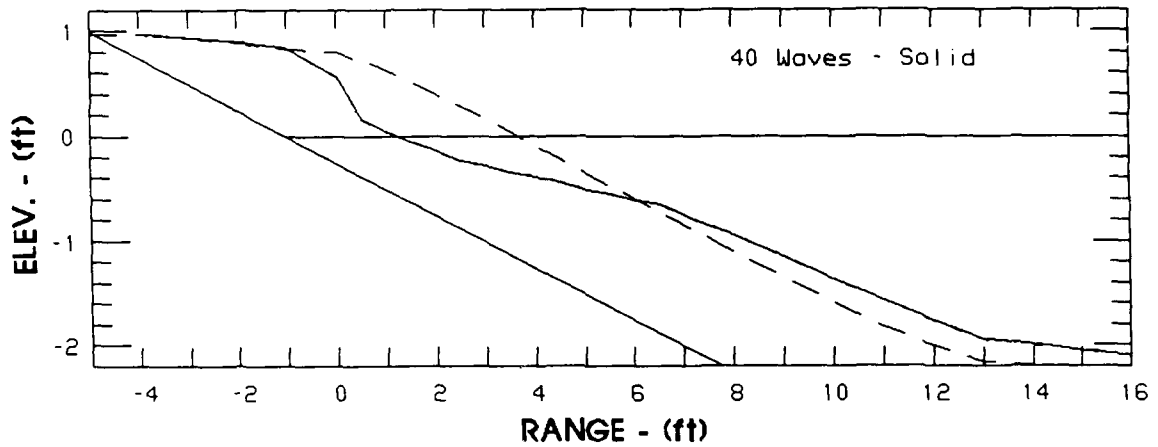


Figure D8. Test T08 profile development (Sheet 1 of 3)

## TEST T08

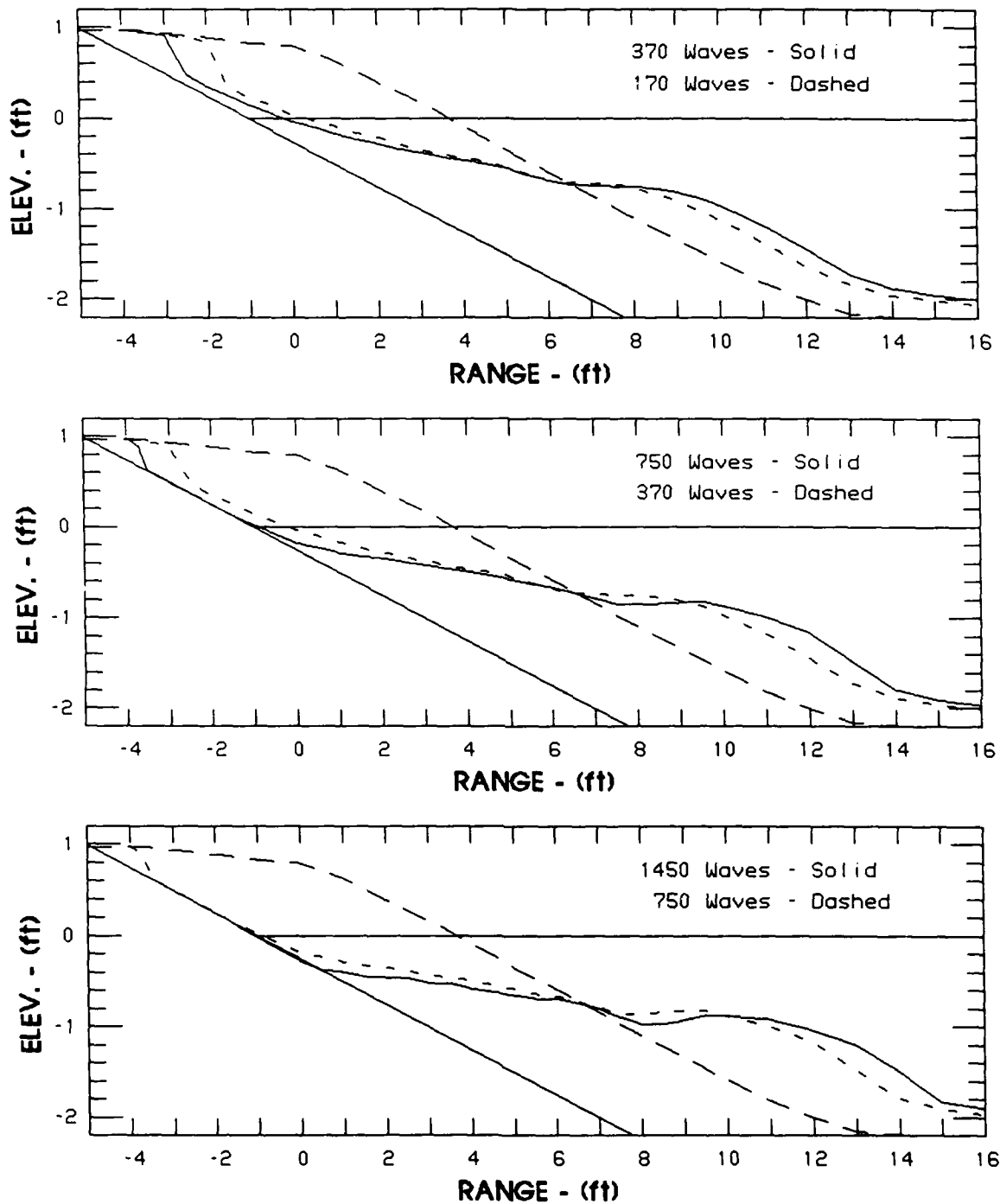


Figure D8. (Sheet 2 of 3)

## TEST T08

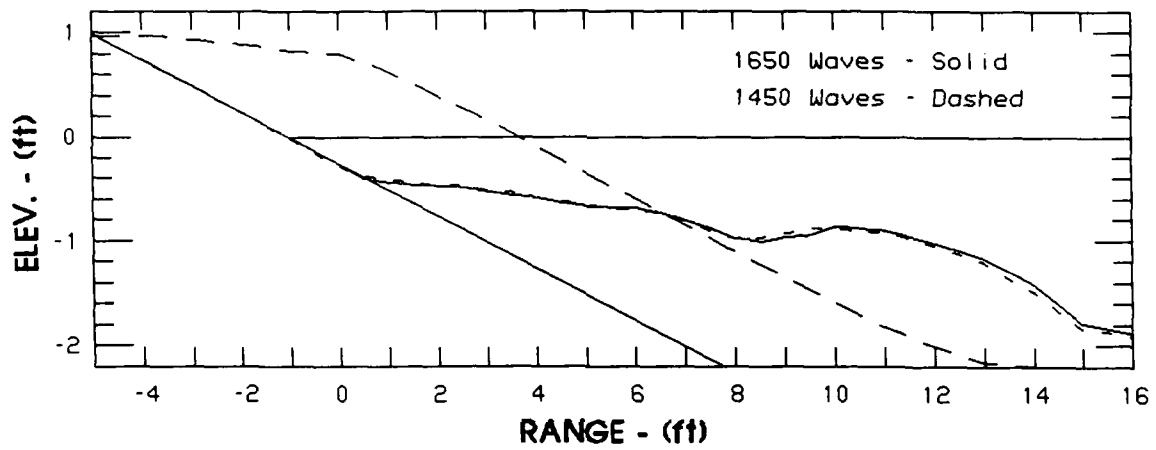


Figure D8. (Sheet 3 of 3)

## TEST T09

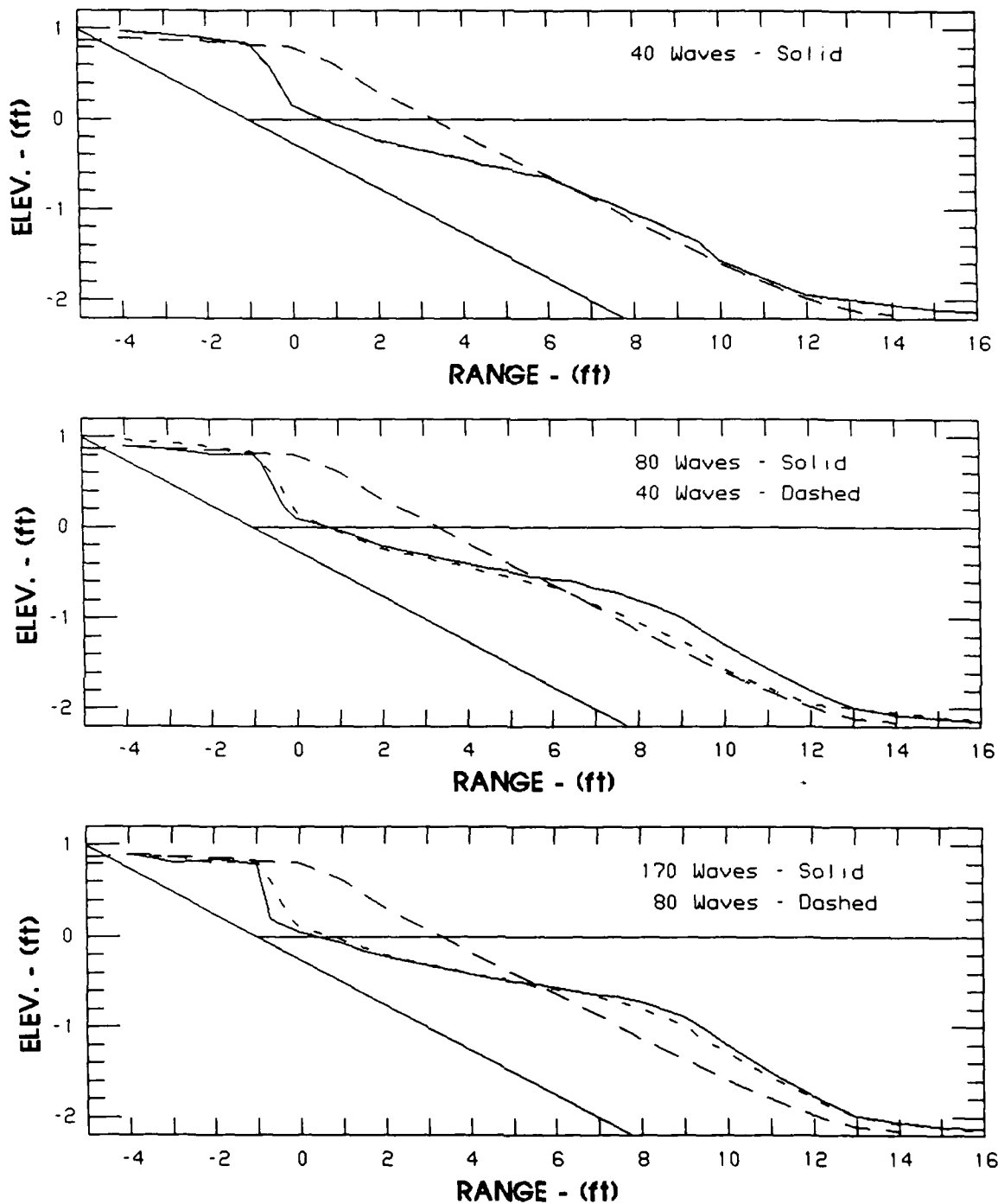


Figure D9. Test T09 profile development (Sheet 1 of 4)

## TEST T09

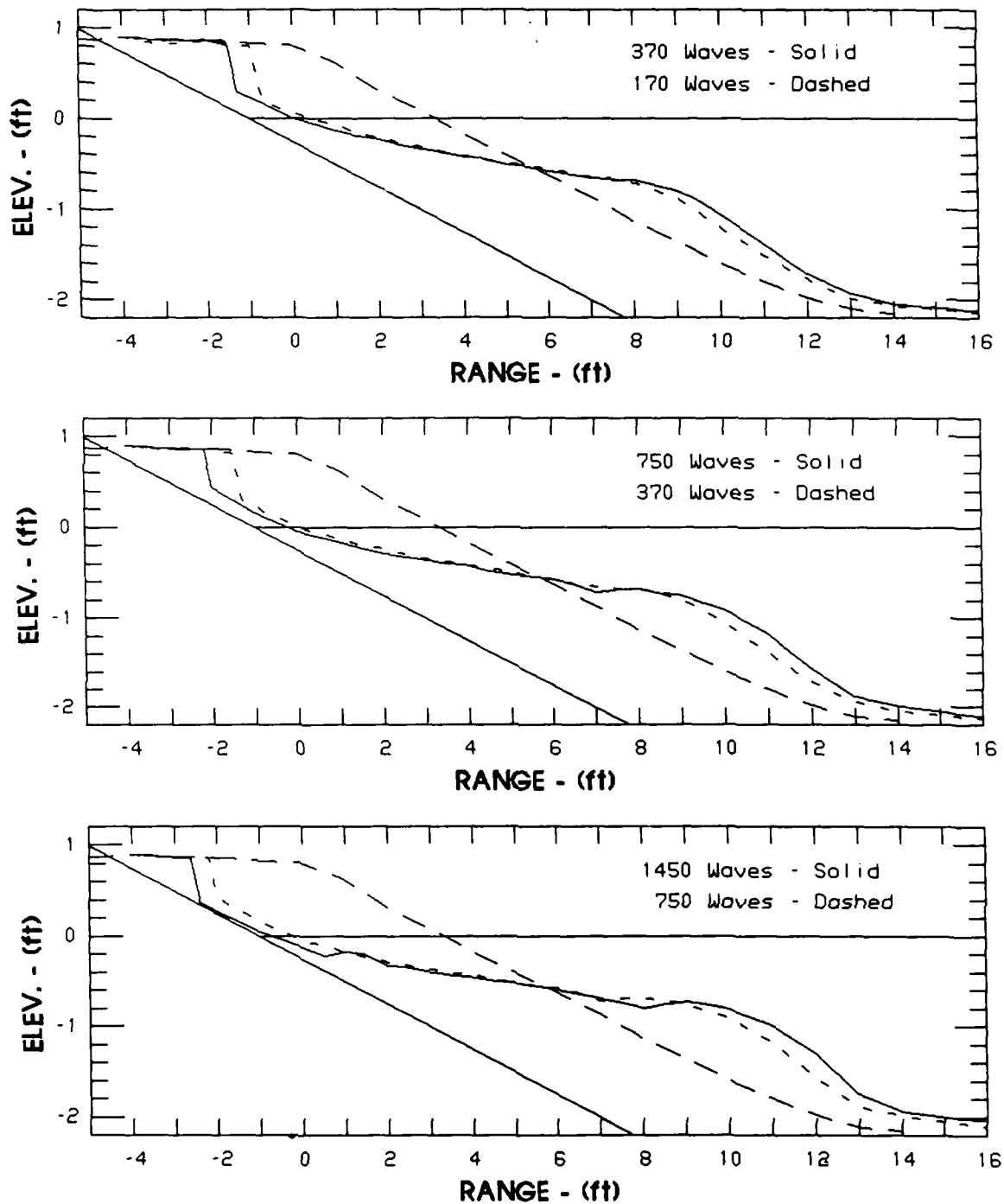


Figure D9. (Sheet 2 of 4)

## TEST T09

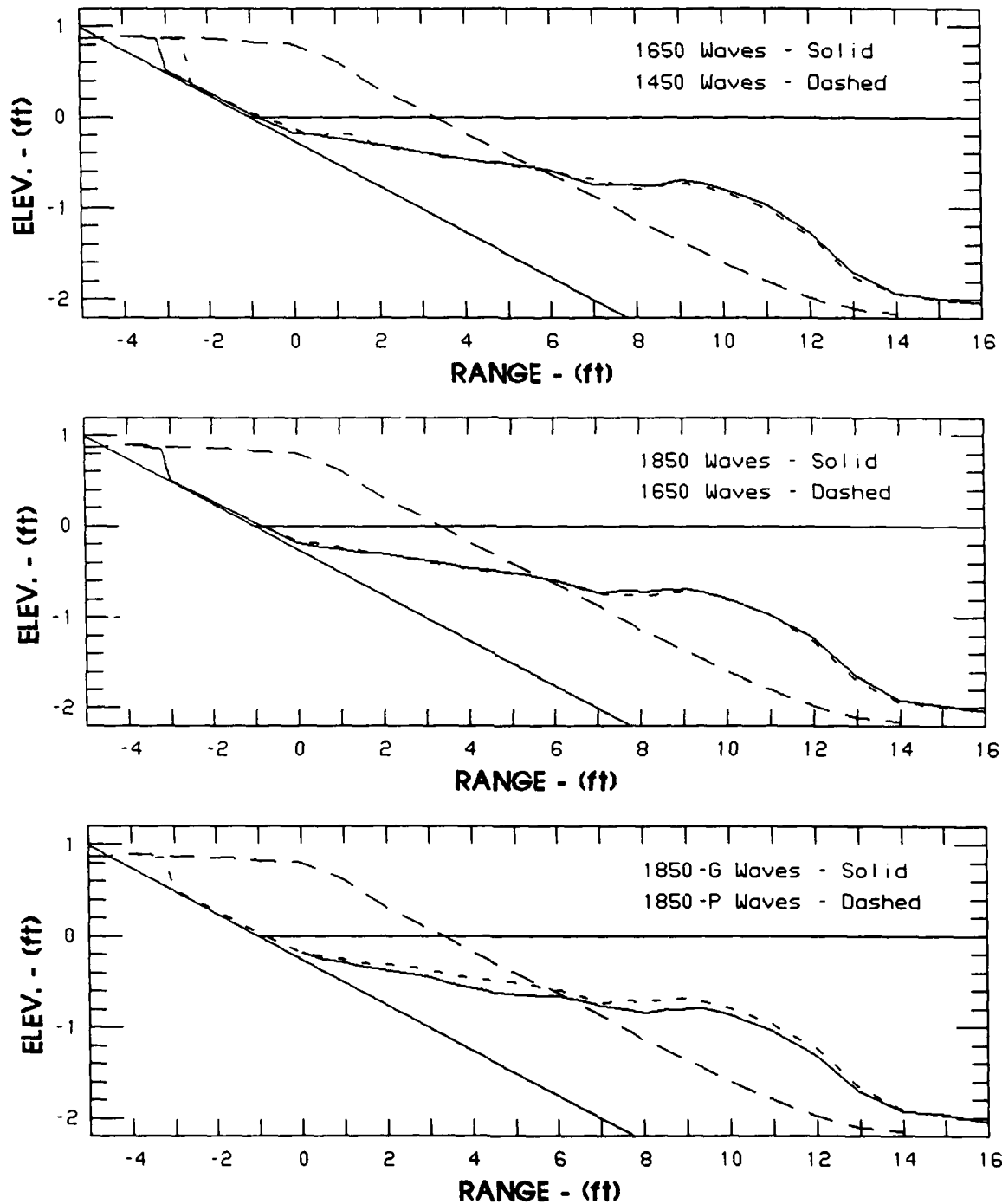


Figure D9. (Sheet 3 of 4)



## TEST T09

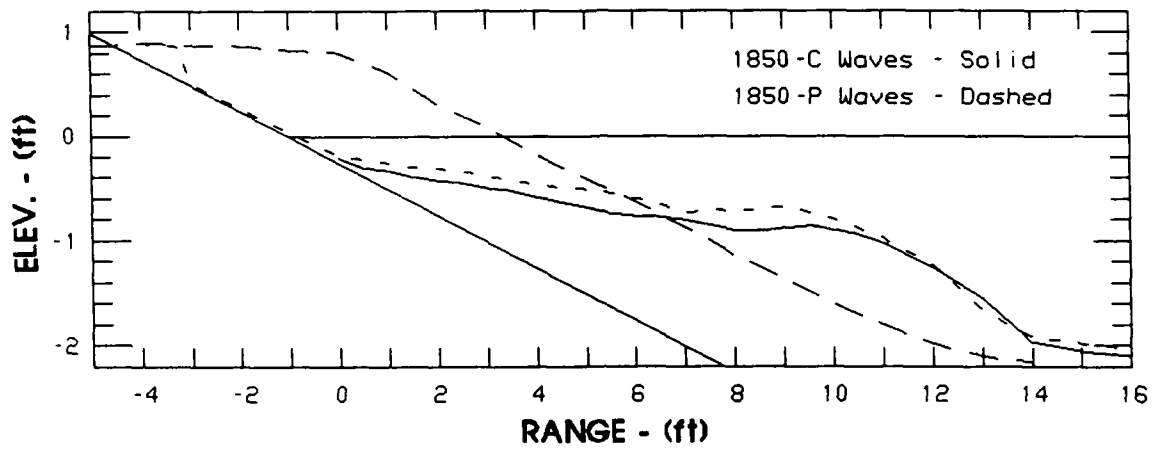


Figure D9. (Sheet 4 of 4)

## TEST T10

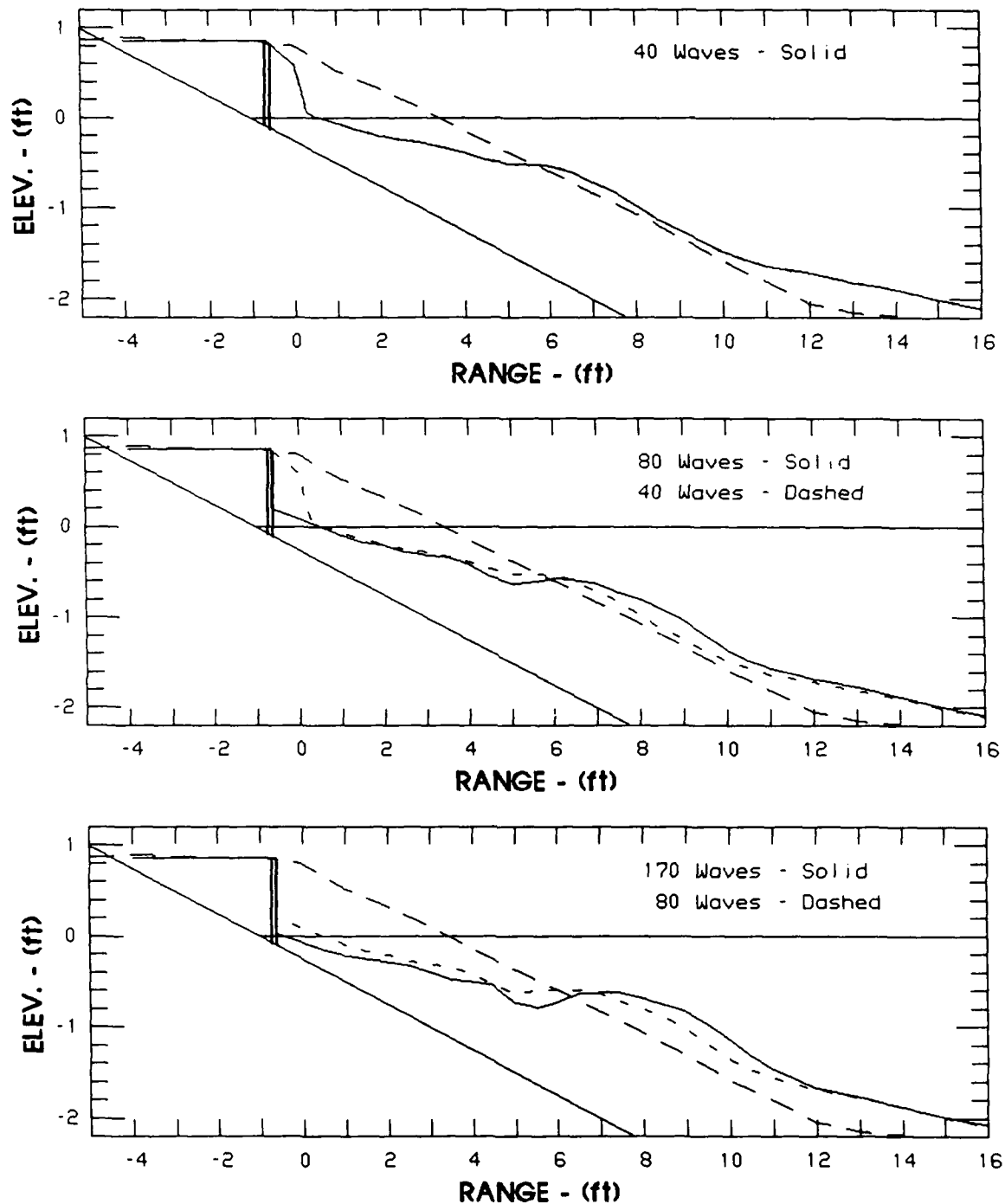


Figure D10. Test T10 profile development (Sheet 1 of 4)

## TEST T10

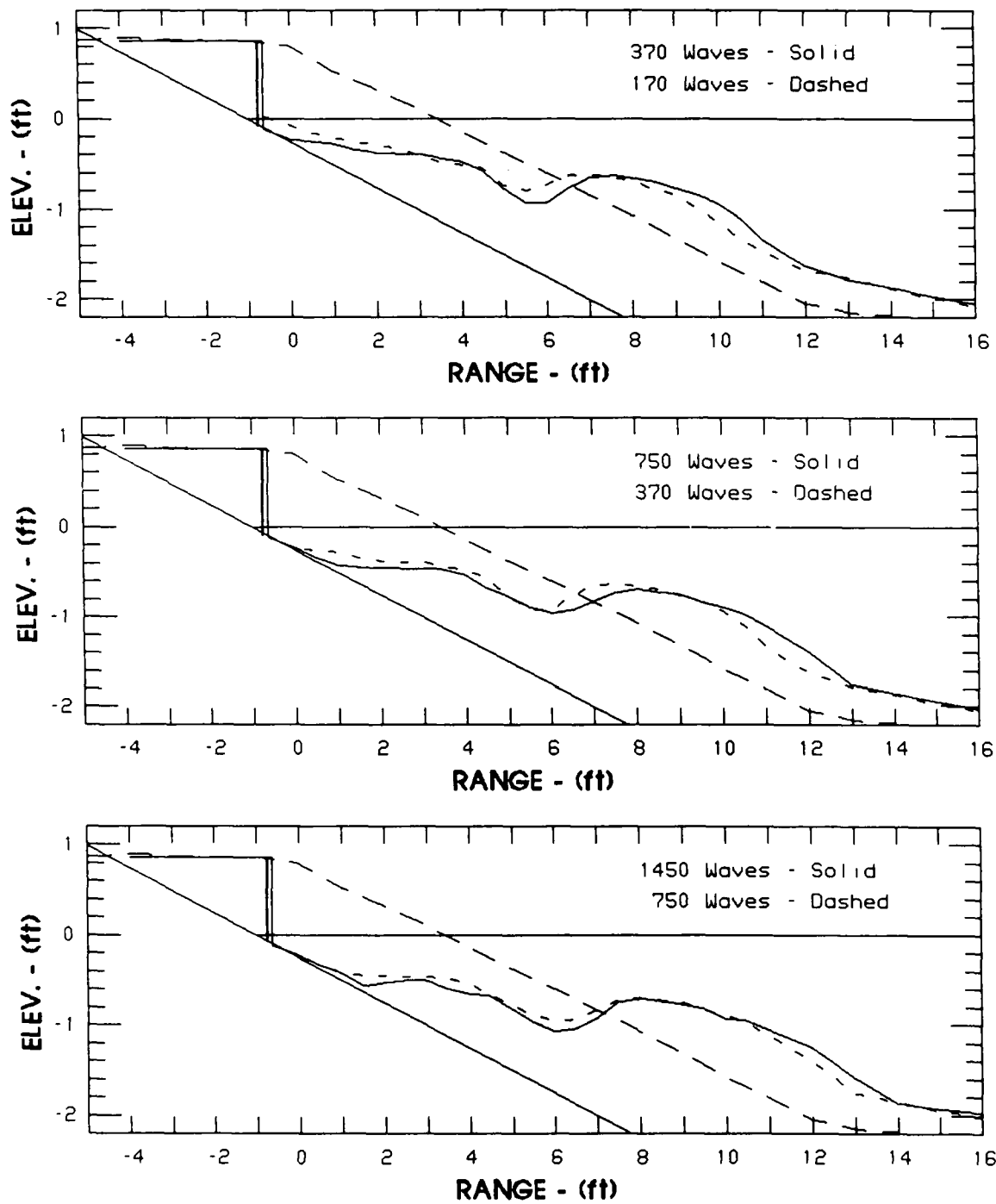


Figure D10. (Sheet 2 of 4)

# TEST T10

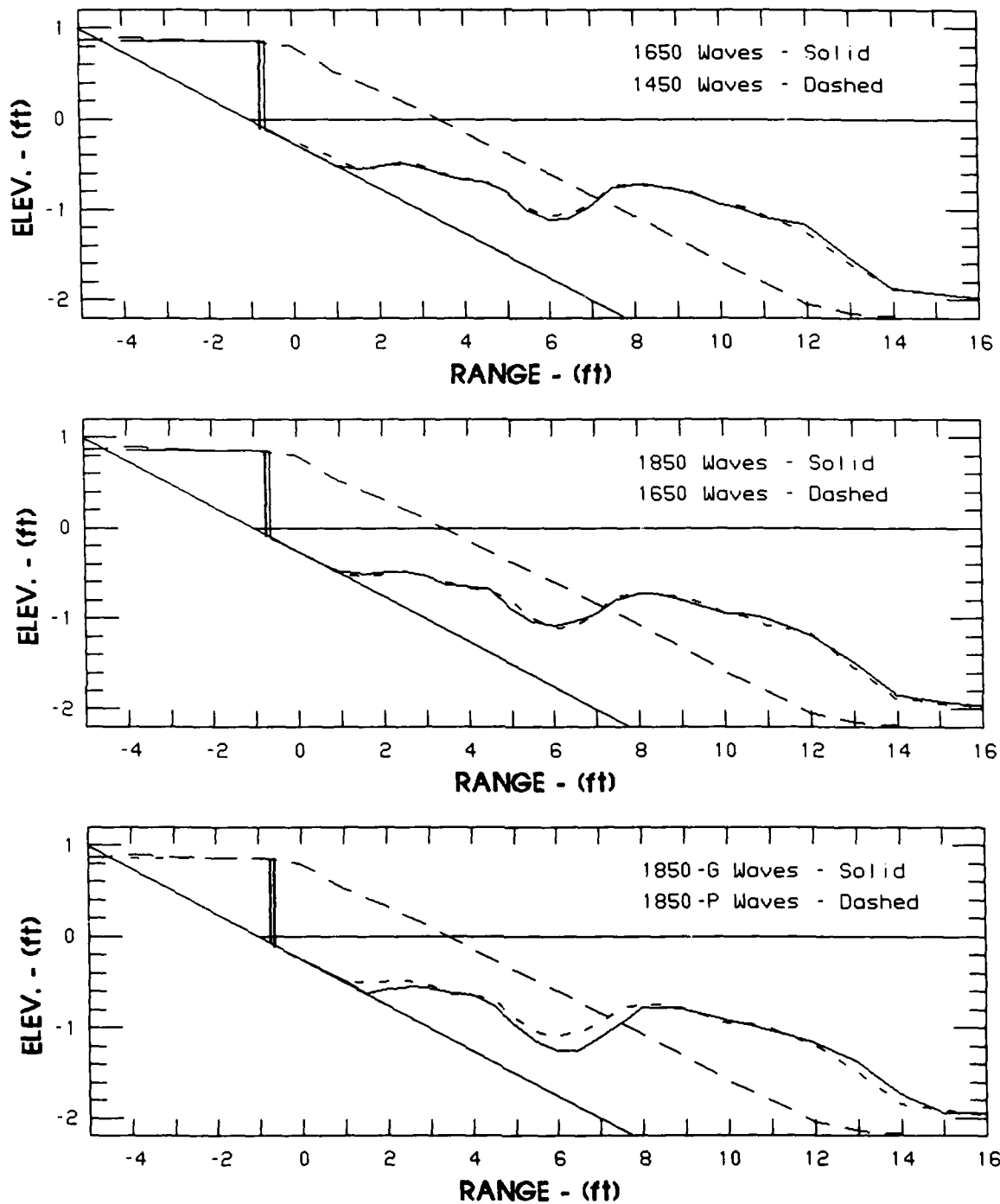


Figure D10. (Sheet 3 of 4)

## TEST T10

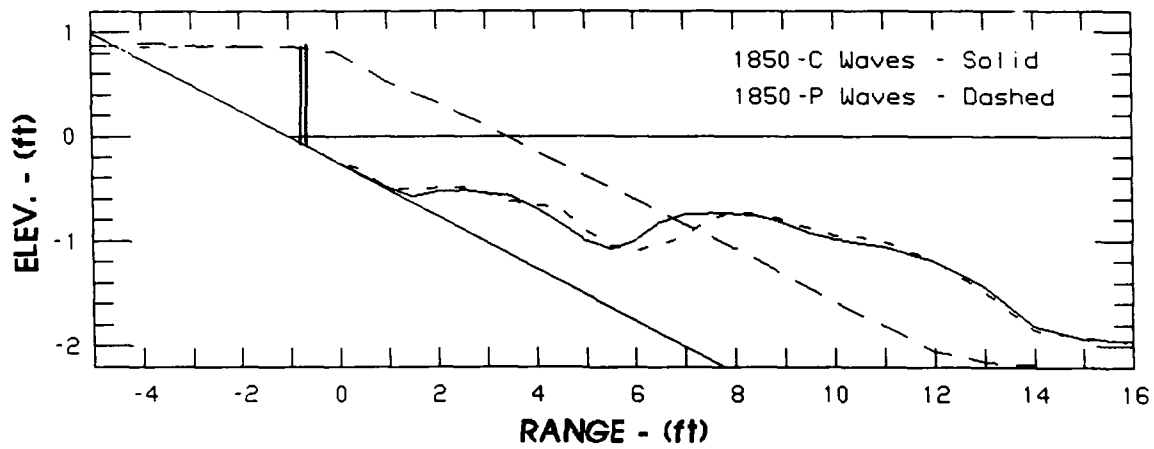


Figure D10. (Sheet 4 of 4)

# TEST T11

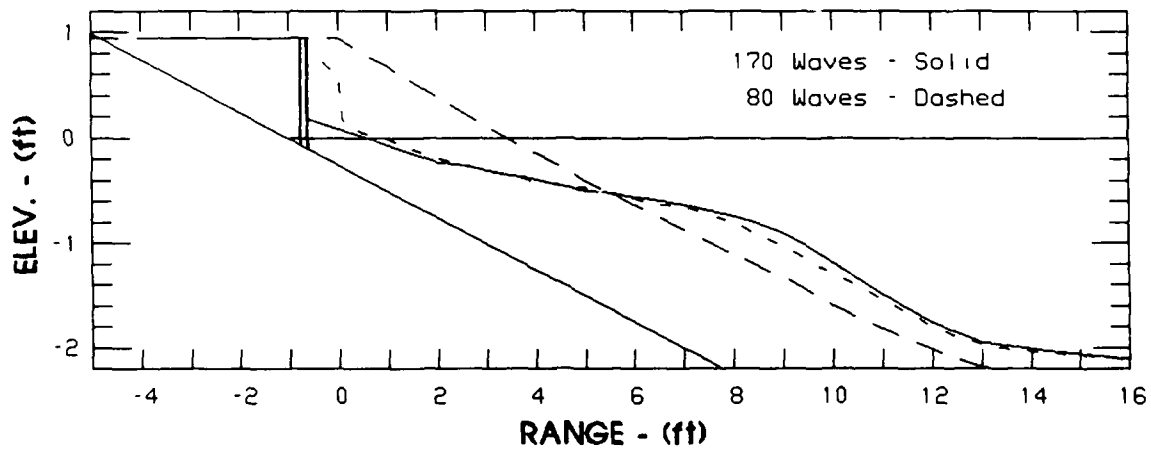
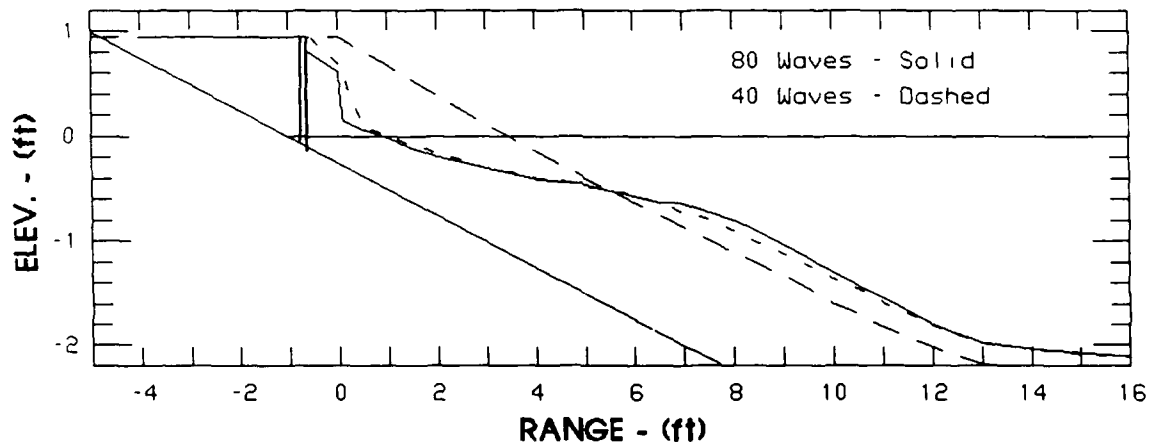
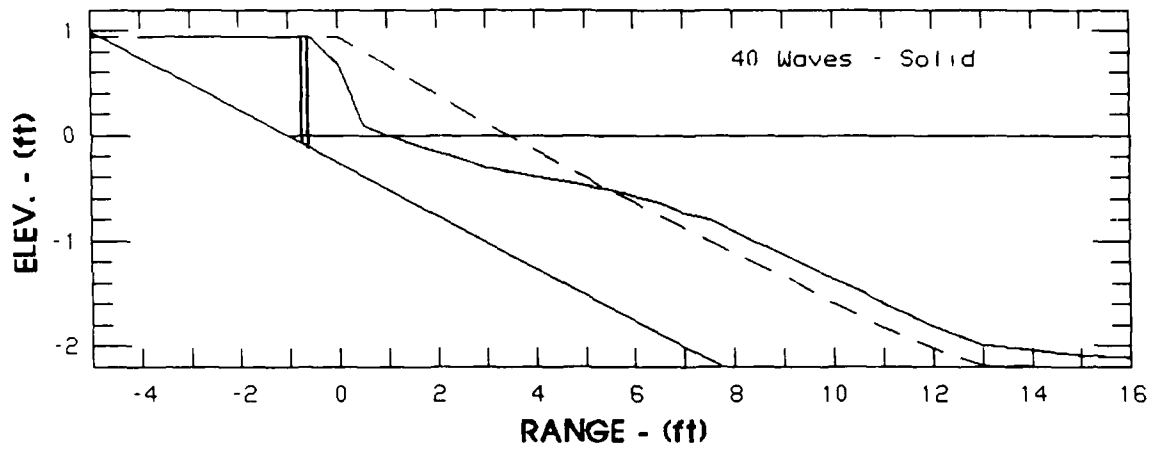


Figure D11. Test T11 profile development (Sheet 1 of 3)

# TEST T11

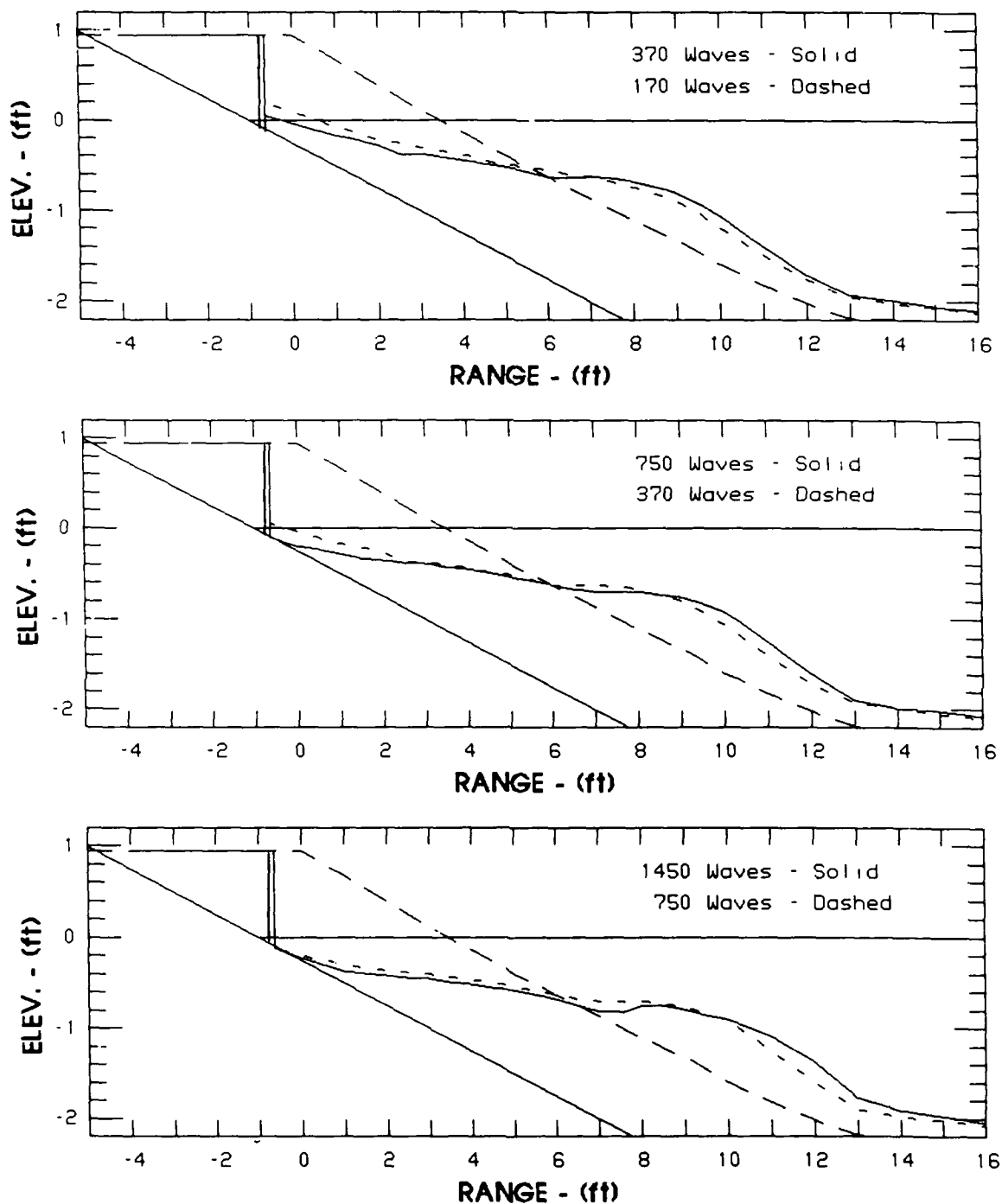


Figure D11. (Sheet 2 of 3)

## TEST T11

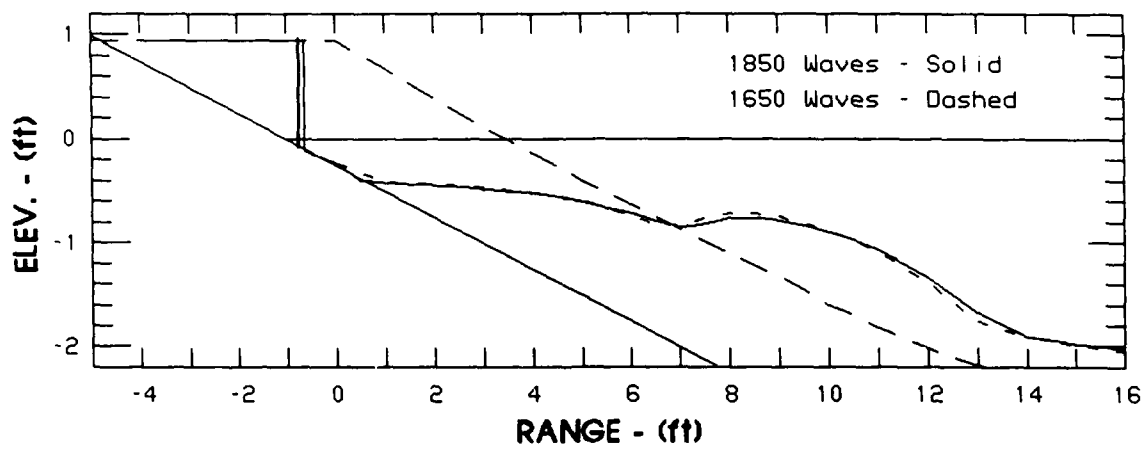
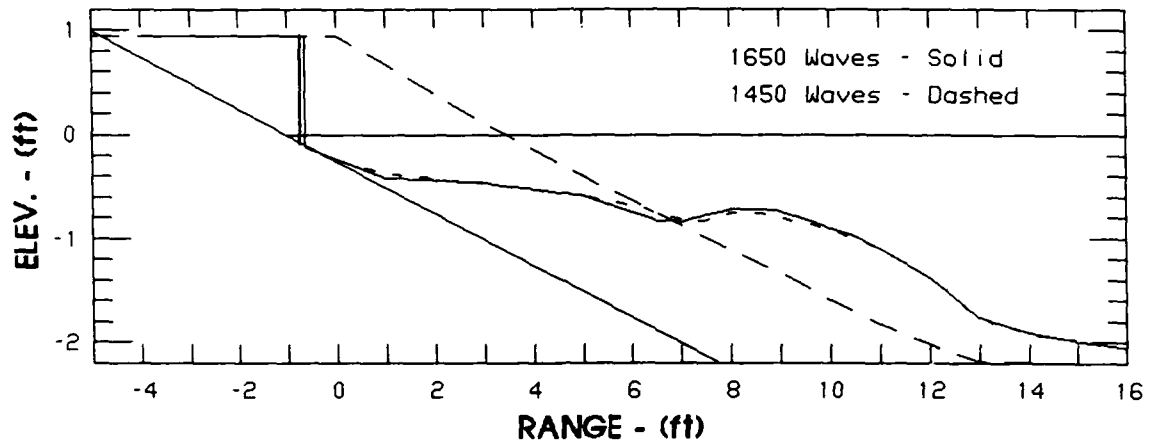


Figure D11. (Sheet 3 of 3)



## TEST T14

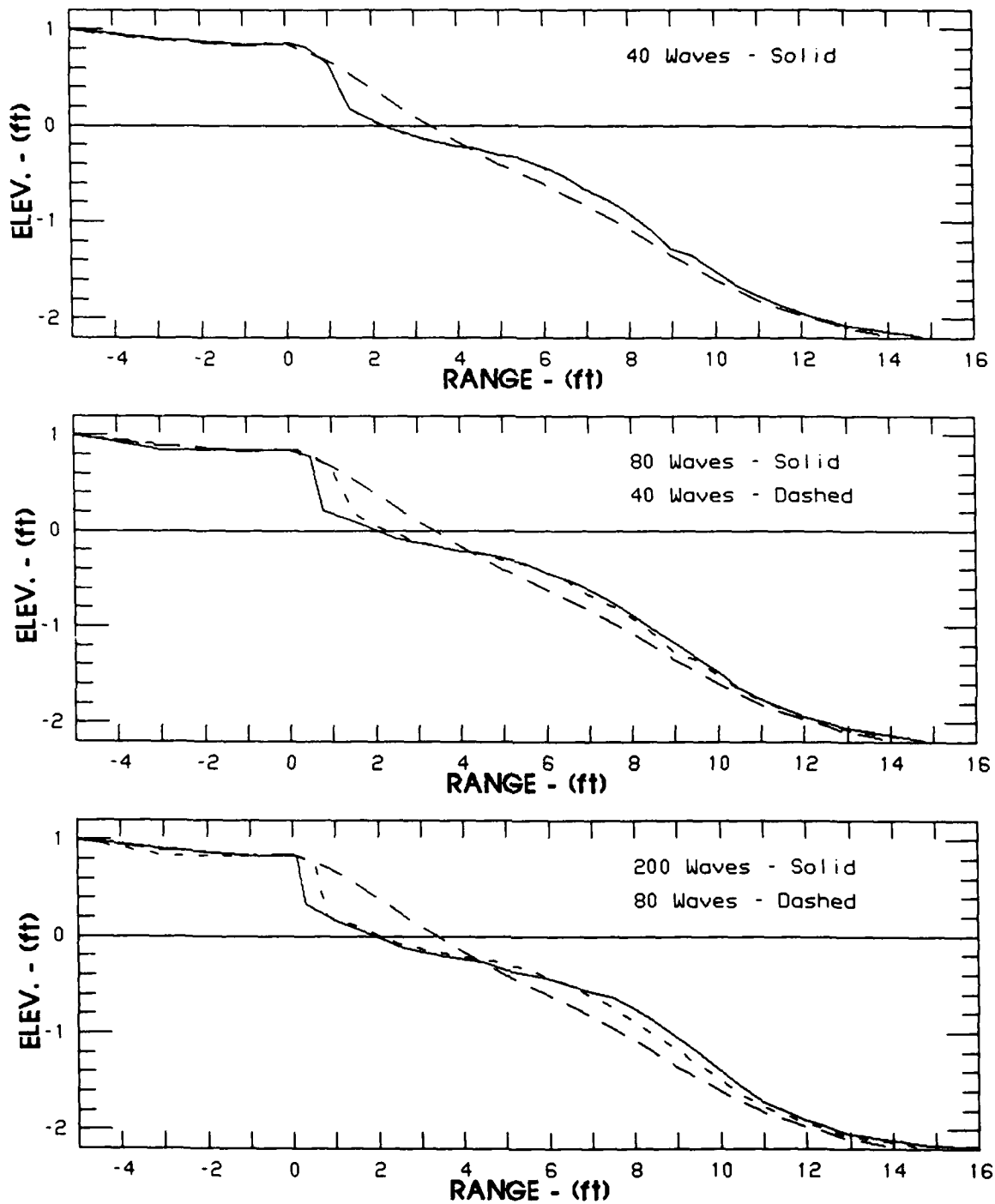


Figure D12. Test T14 profile development (Sheet 1 of 6)

## TEST T14

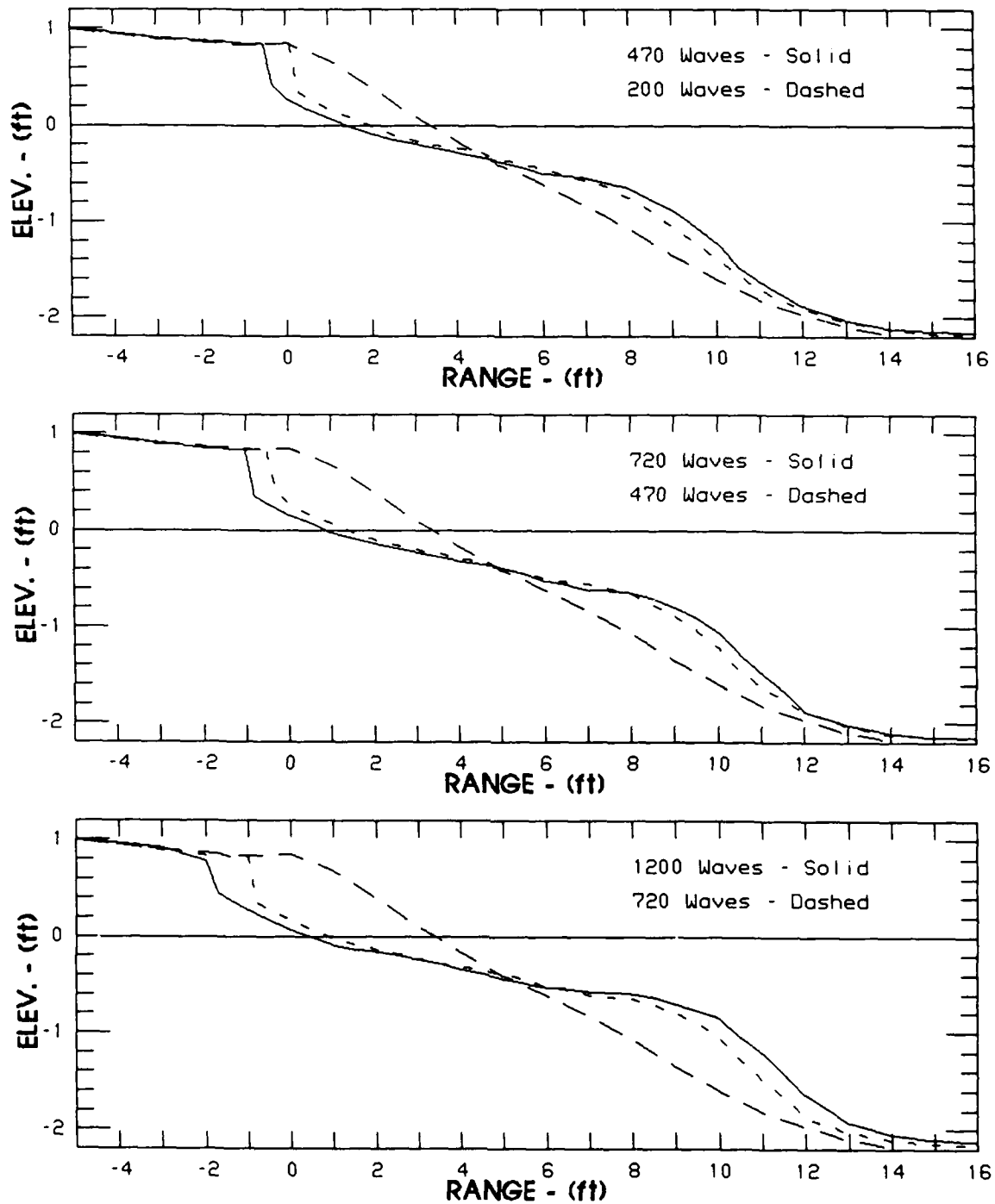


Figure D12. (Sheet 2 of 6)

# TEST T14

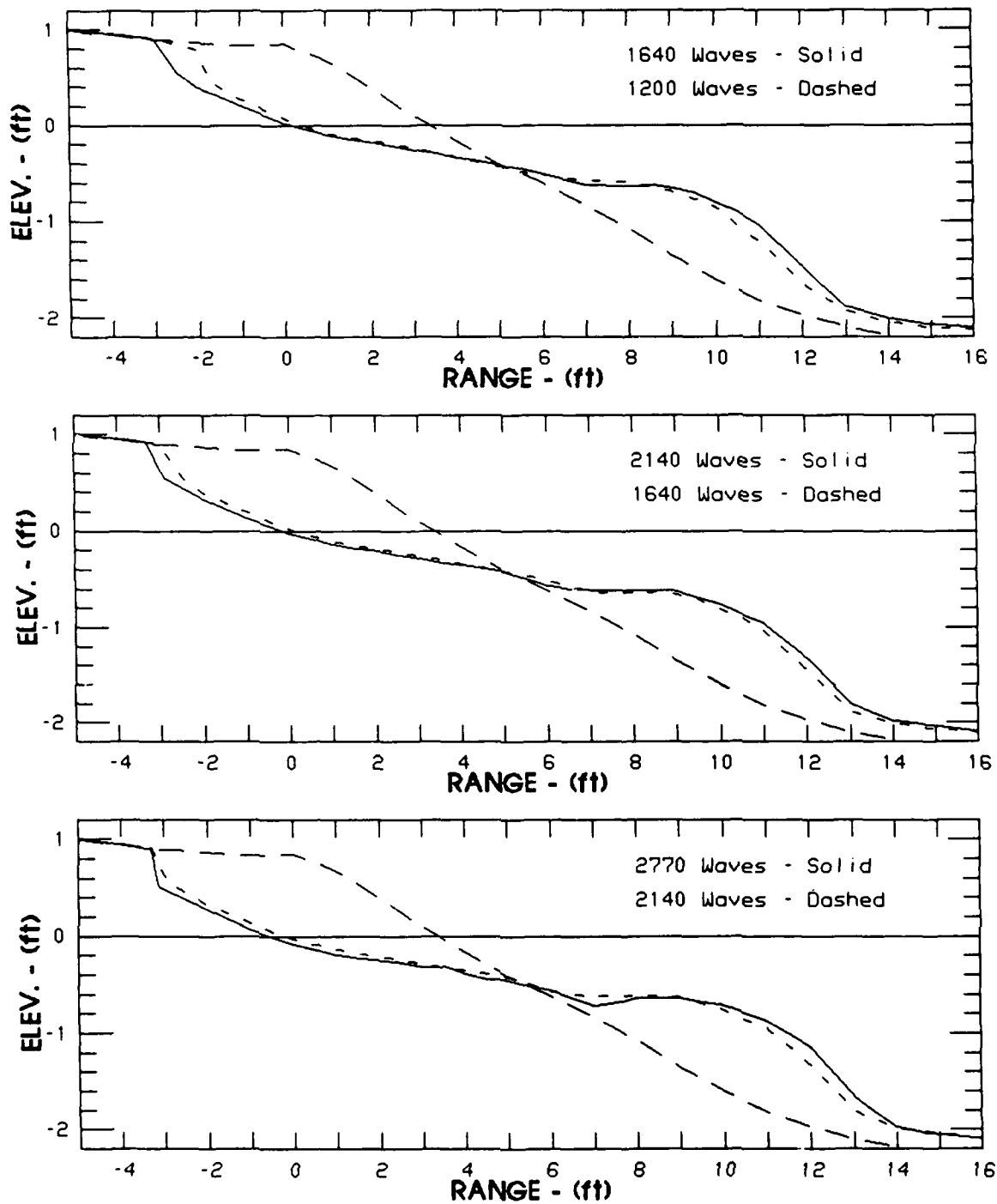


Figure D12. (Sheet 3 of 6)

## TEST T14

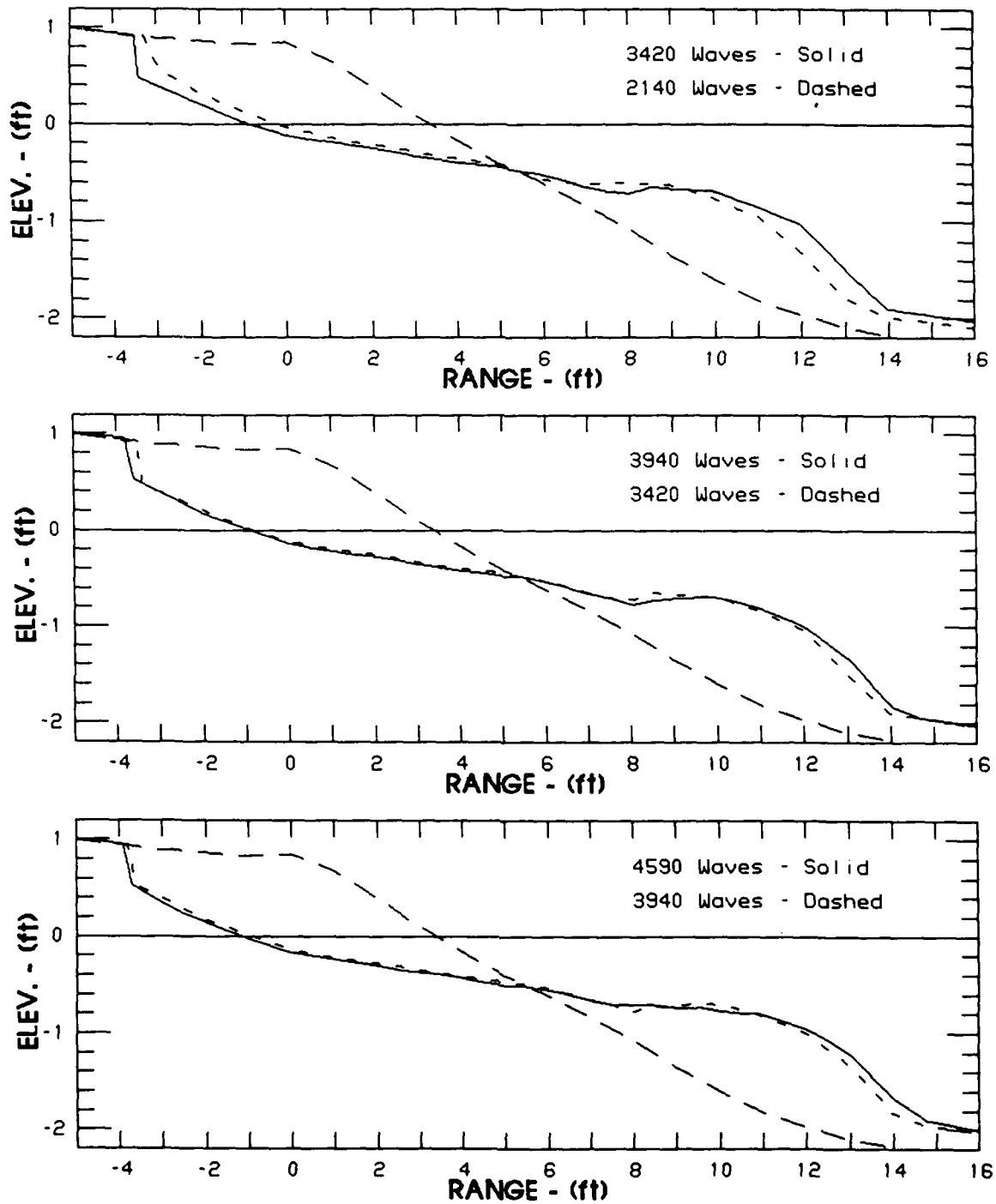


Figure D12. (Sheet 4 of 6)

## TEST T14

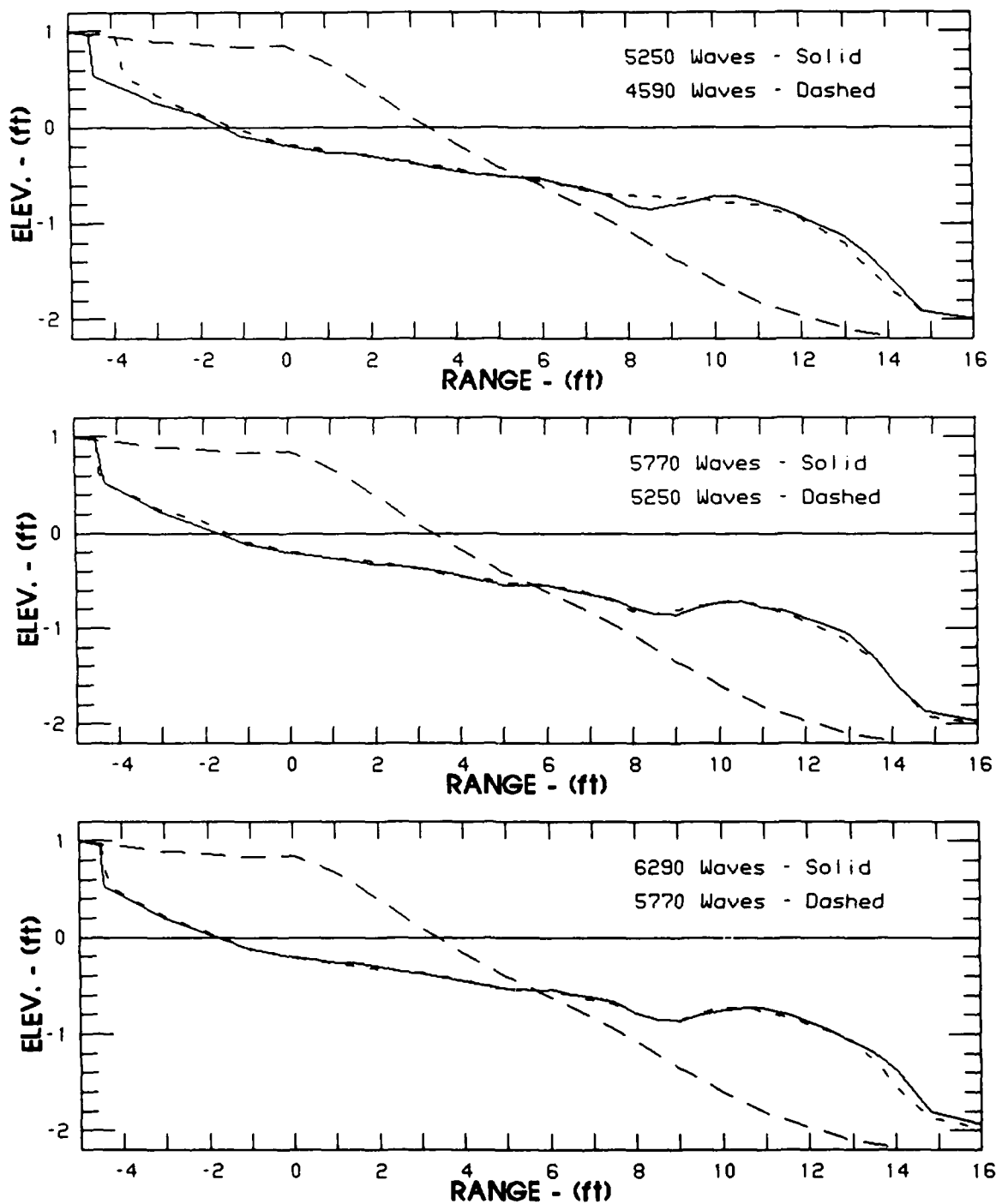


Figure D12. (Sheet 5 of 6)

## TEST T14

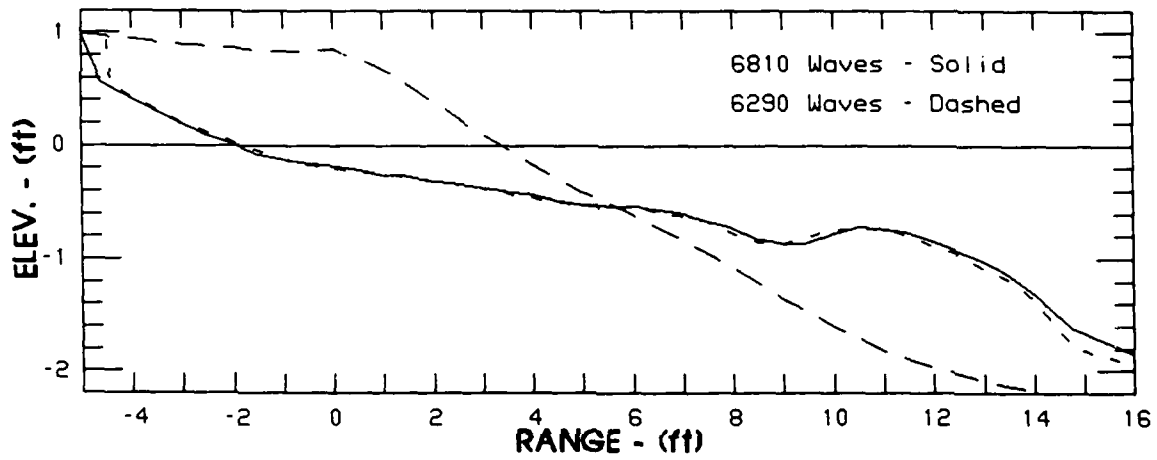


Figure D12. (Sheet 6 of 6)

## APPENDIX E: PLOTS OF PROFILE COMPARISONS

The plots shown in this appendix are comparisons between various profiles from both the midscale and the Grosser Wellenkanal (GWK) prototype-scale tests. Midscale physical model profiles are scaled to prototype units when compared with GWK prototype profiles. Profile comparisons between midscale tests are plotted in model units. All profiles are center-line profiles except those denoted with an uppercase G (glass sidewall) or an uppercase C (concrete sidewall).

Description of Comparison	Figure Number
Test T01 versus prototype	E1
Test T03 versus prototype	E2
Test T04 versus prototype	E3
Test T05 versus prototype	E4
Test T06 versus prototype	E5
Test T07 versus prototype	E6
Irregular test T14 versus prototype	E7
Repeatability test, T01 versus T02	E8
Wave height perturbation, T04 versus T03	E9
Wave period perturbation, T07 versus T03	E10
Equal H/wT parameters, T04 versus T07	E11
Initial profile at 40 waves, T06 versus T03	E12
Reduced sediment comparison, T01 versus T03	E13
Absorbing wave board test, T05 versus T03	E14
Irregular wave comparison, $H_{1/3}$ equals $H_{mono}$	E15
Irregular wave comparison, $H_{1/3}$ equals $141\% H_{mono}$	E16
Irregular wave perturbation, T09 versus T08	E17
Irregular wave repeatability, T12 versus T08	E18
Seawall impacts under regular waves, T10 versus T03	E19
Seawall impacts under irregular waves, T11 versus T09	E20
Seawall irregular wave comparison, $H_{1/3}$ equals $H_{mono}$	E21

## TEST T01 vs. PROTOTYPE

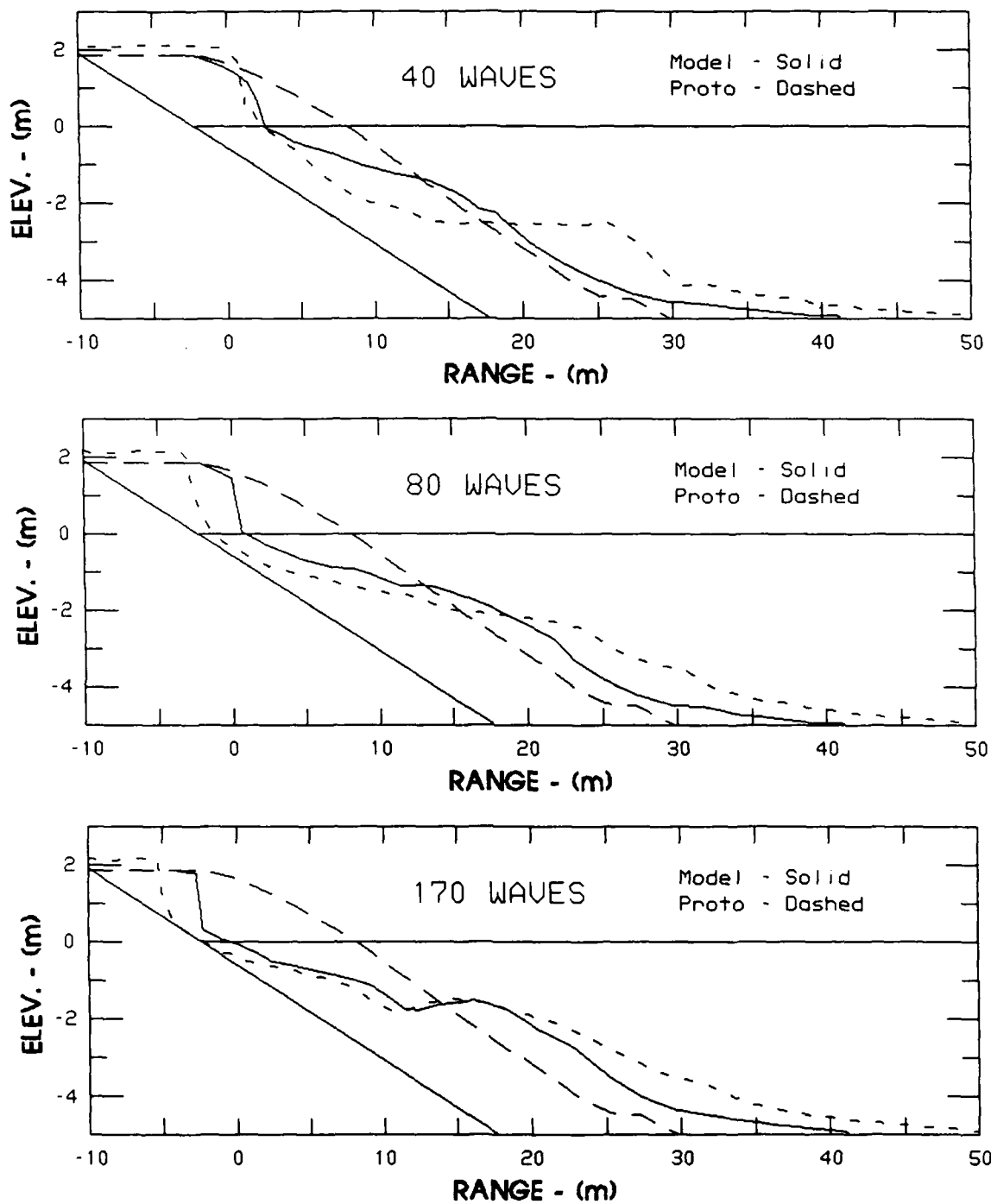


Figure E1. Test T01 versus prototype (Sheet 1 of 3)



## TEST T01 vs. PROTOTYPE

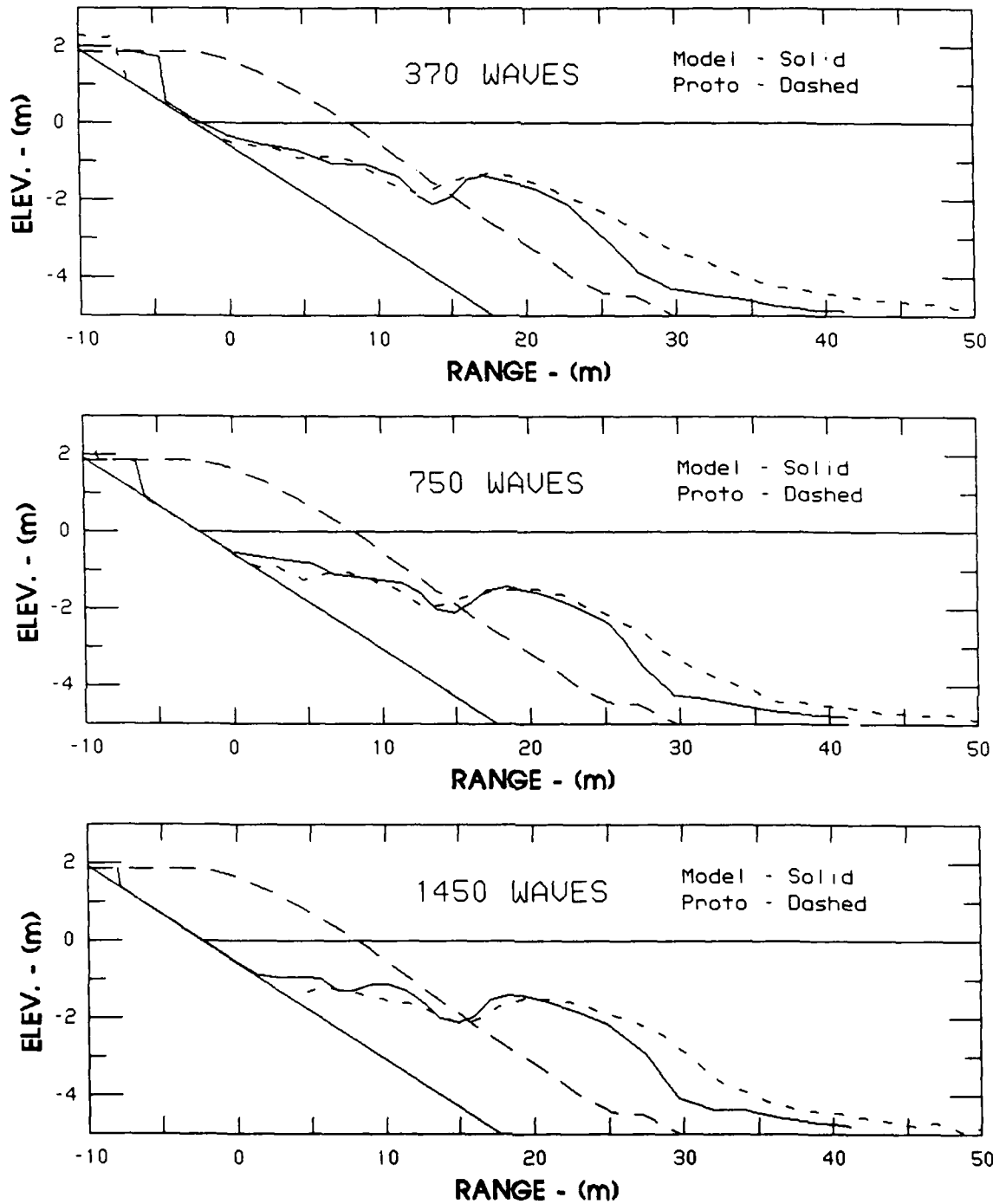


Figure E1. (Sheet 2 of 3)

## TEST T01 vs. PROTOTYPE

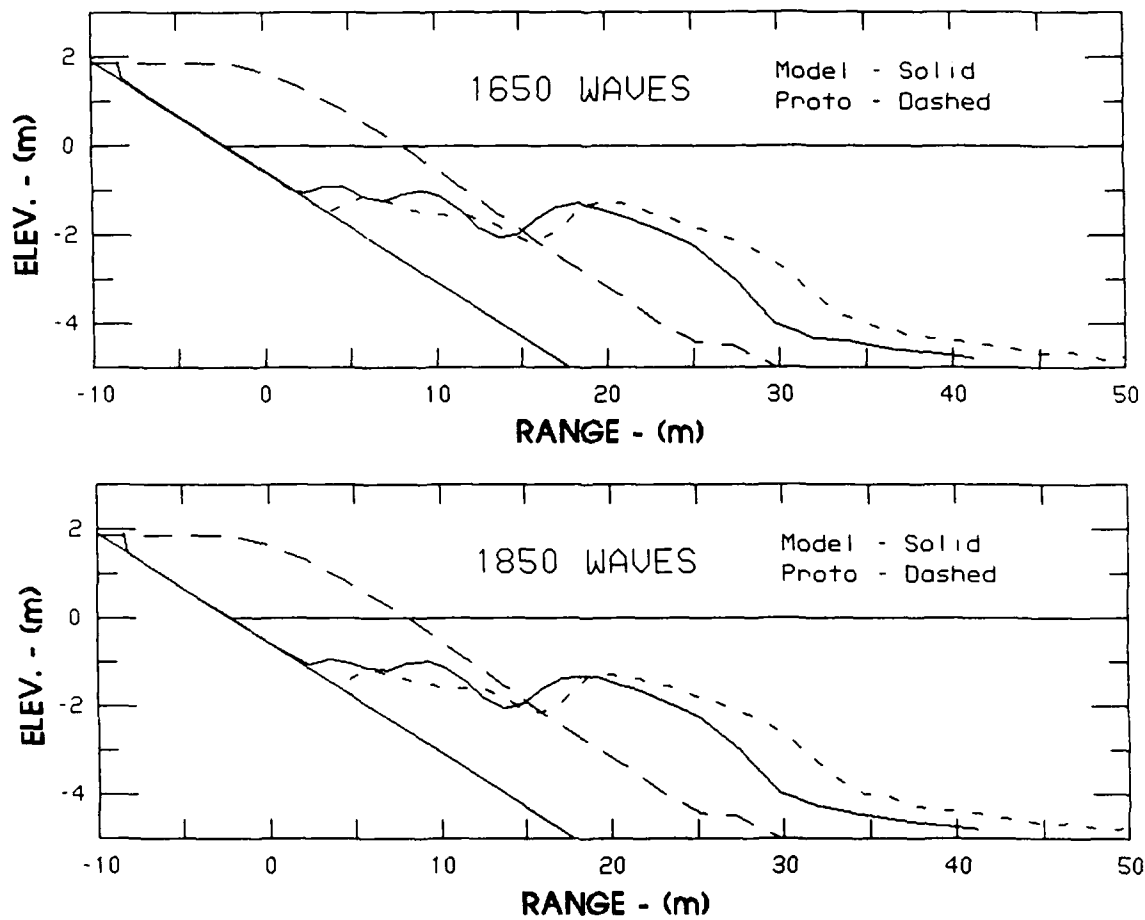


Figure E1. (Sheet 3 of 3)

## TEST T03 vs. PROTOTYPE

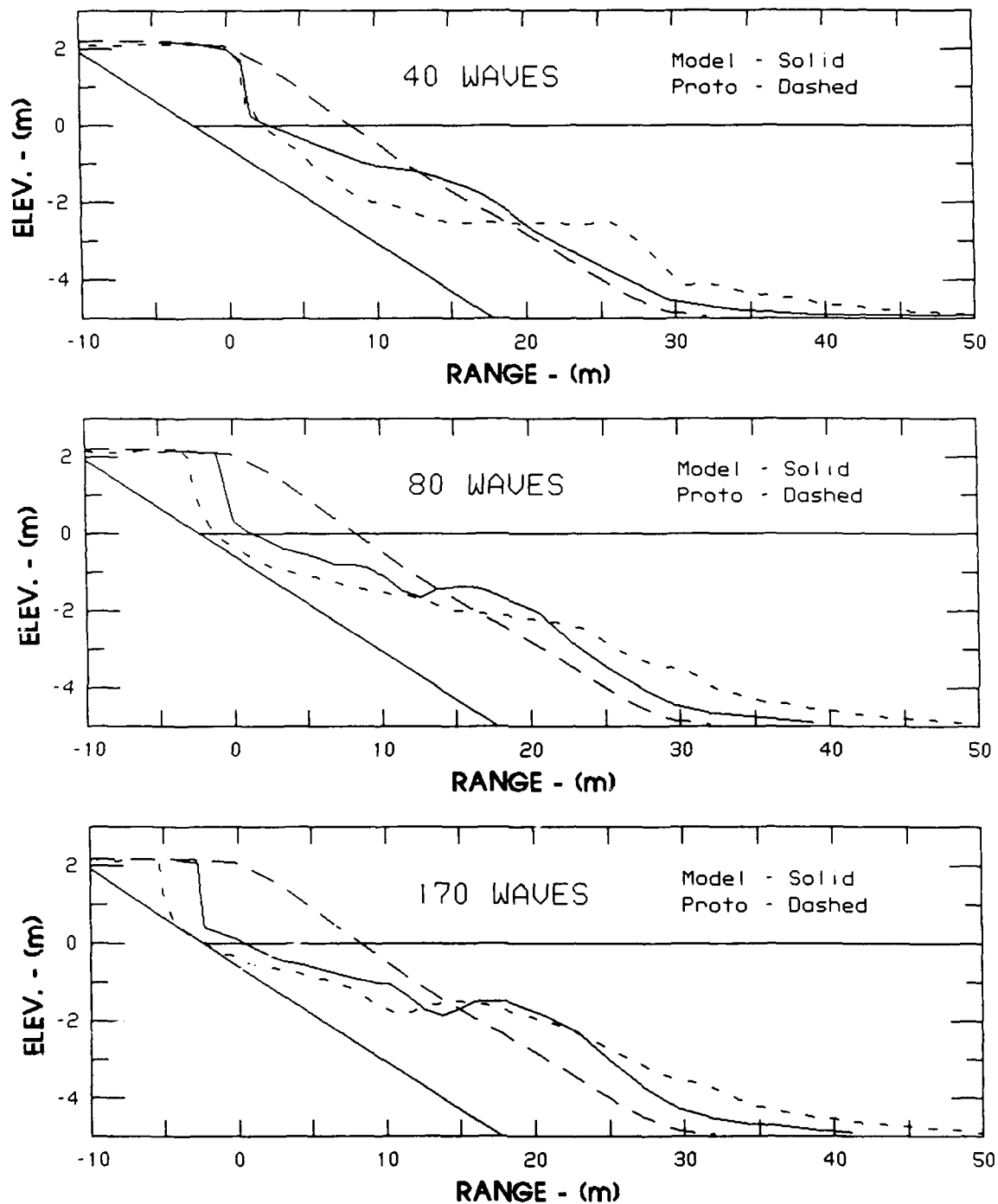


Figure E2. Test T03 versus prototype (Sheet 1 of 3)

## TEST T03 vs. PROTOTYPE

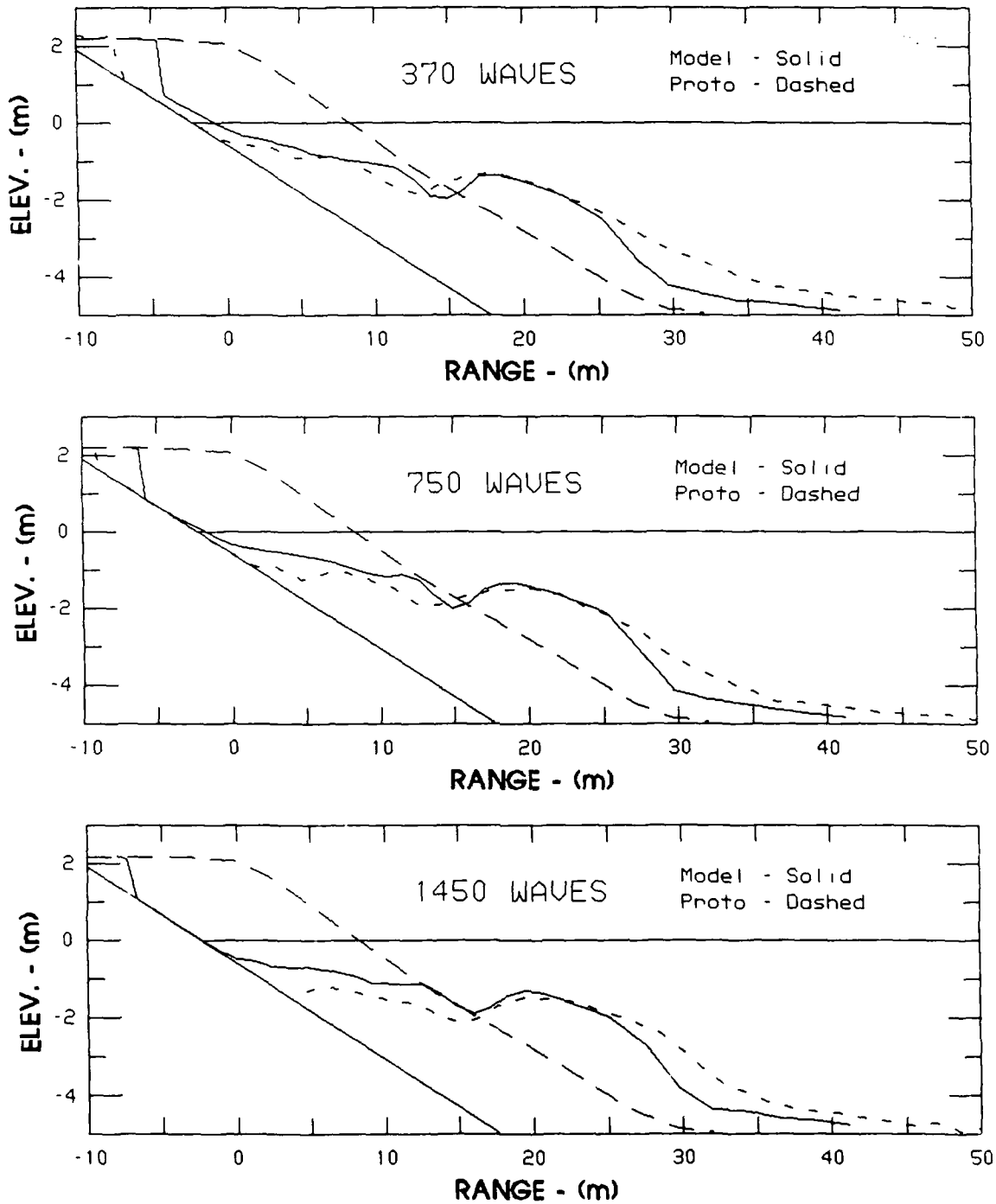


Figure E2. (Sheet 2 of 3)

## TEST T03 vs. PROTOTYPE

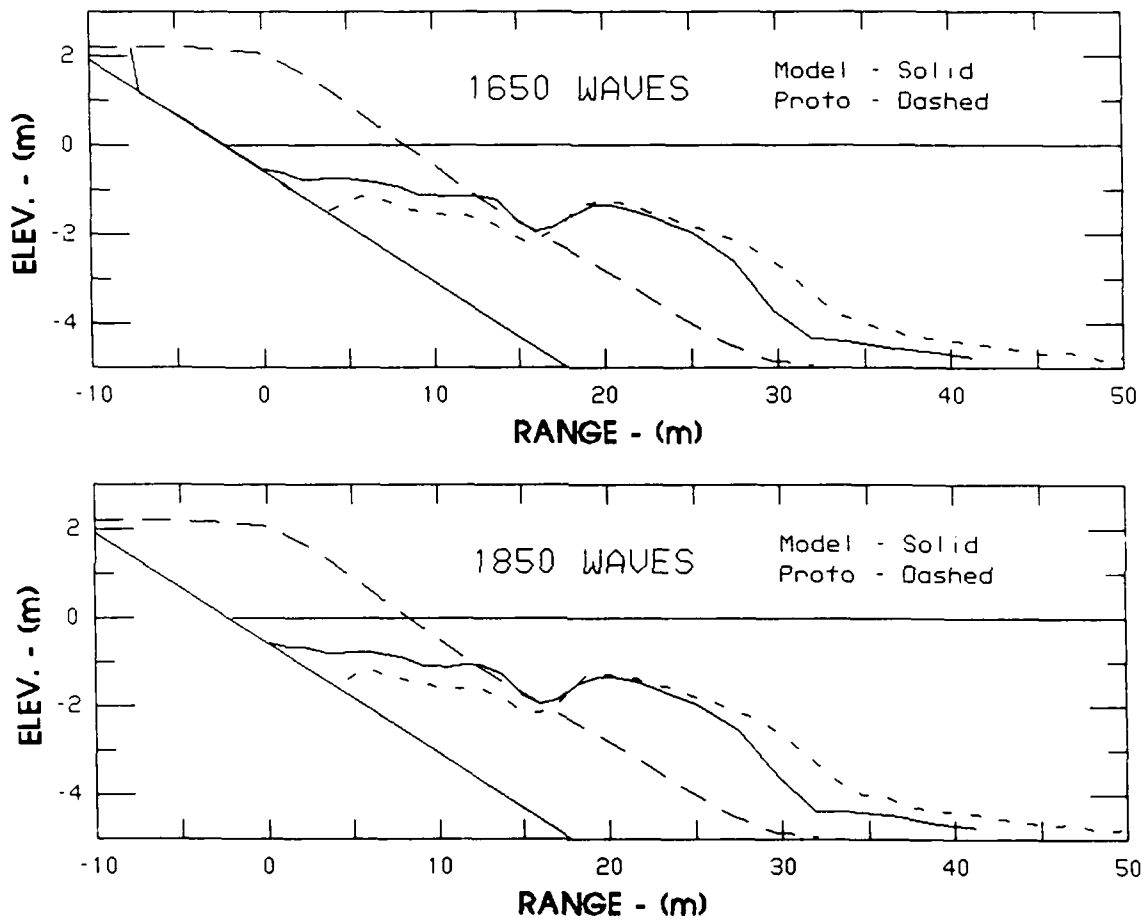


Figure E2. (Sheet 3 of 3)

## TEST T04 vs. PROTOTYPE

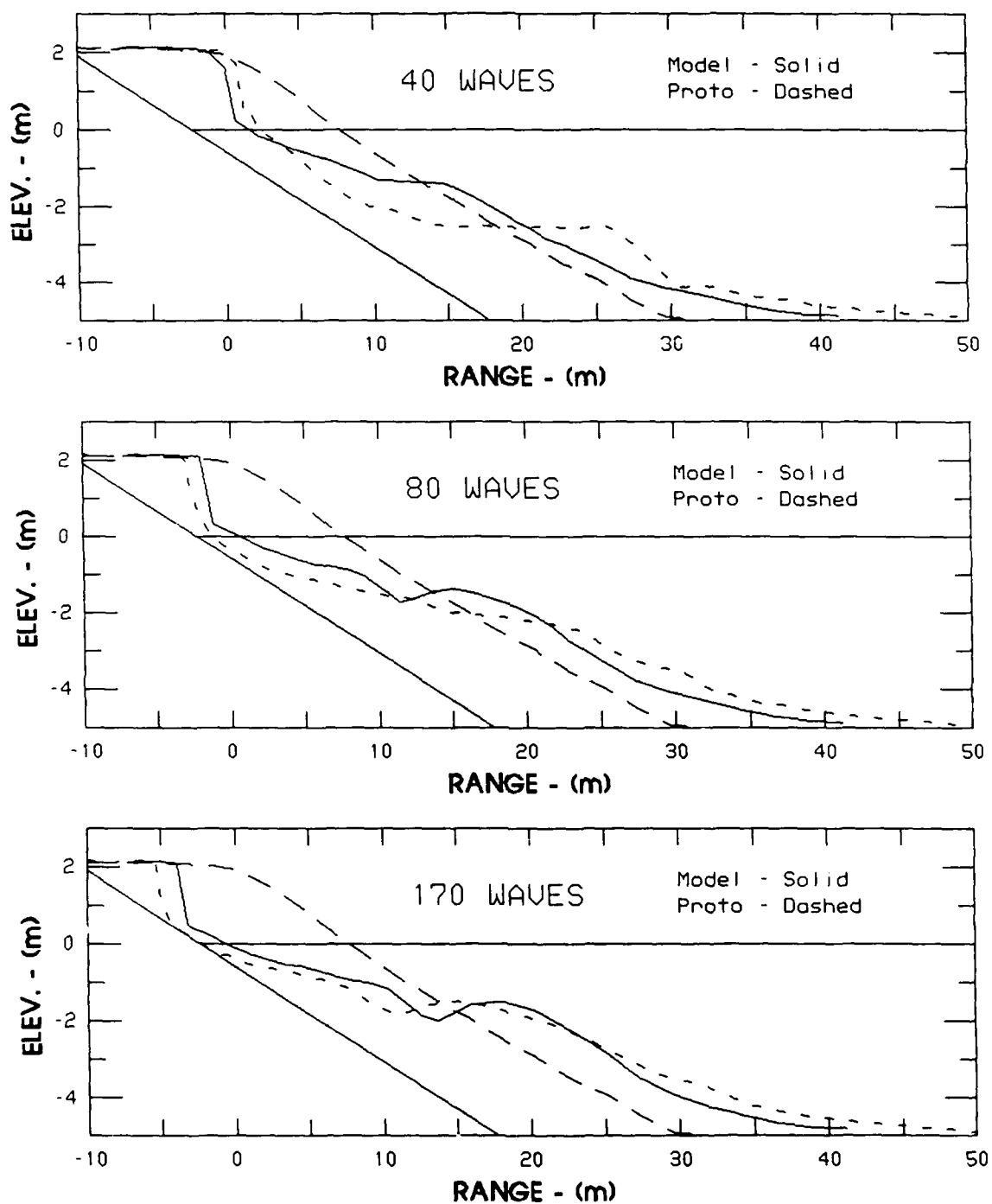


Figure E3. Test T04 versus prototype (Sheet 1 of 3)

## TEST T04 vs. PROTOTYPE

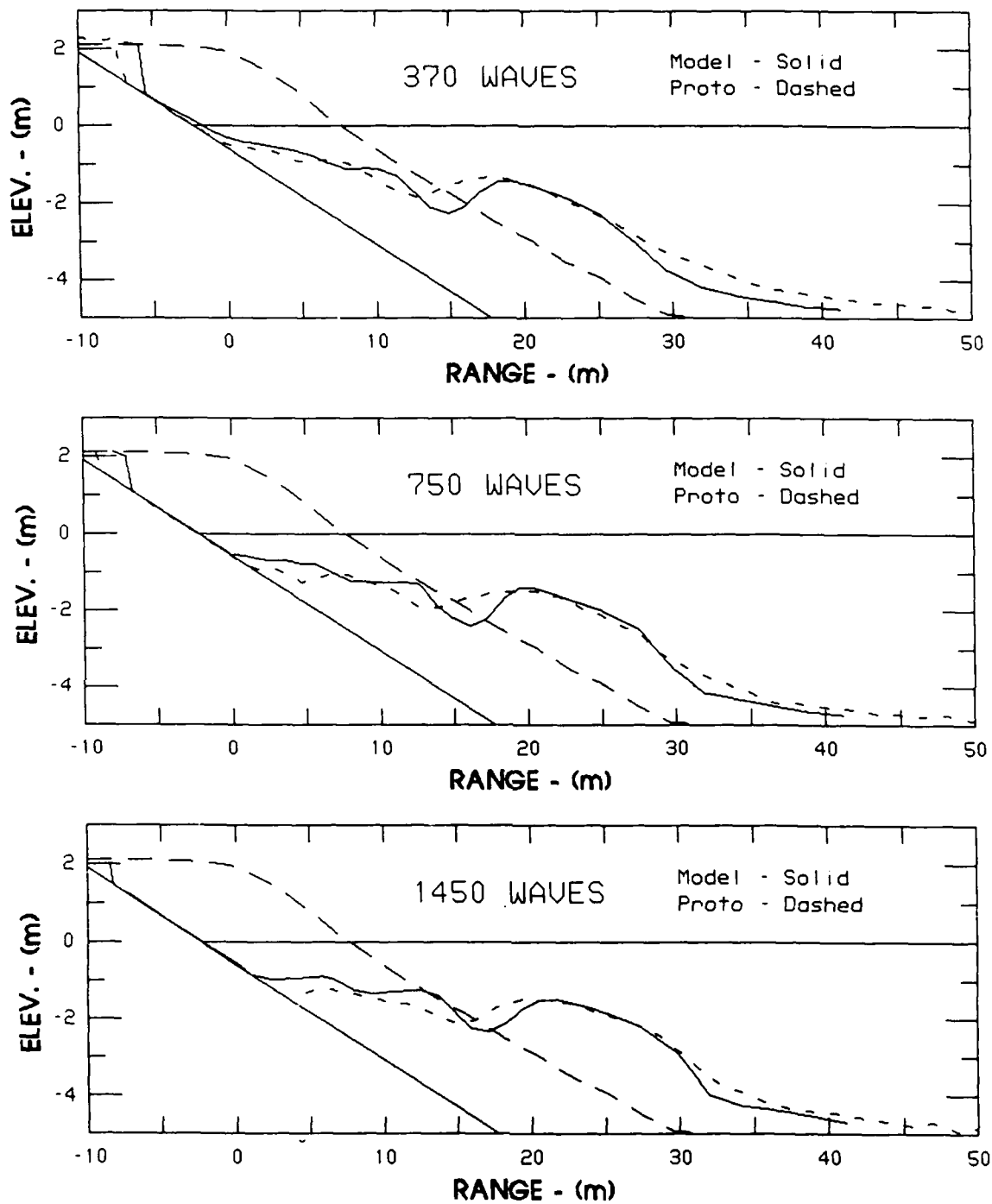


Figure E3. (Sheet 2 of 3)

## TEST T04 vs. PROTOTYPE

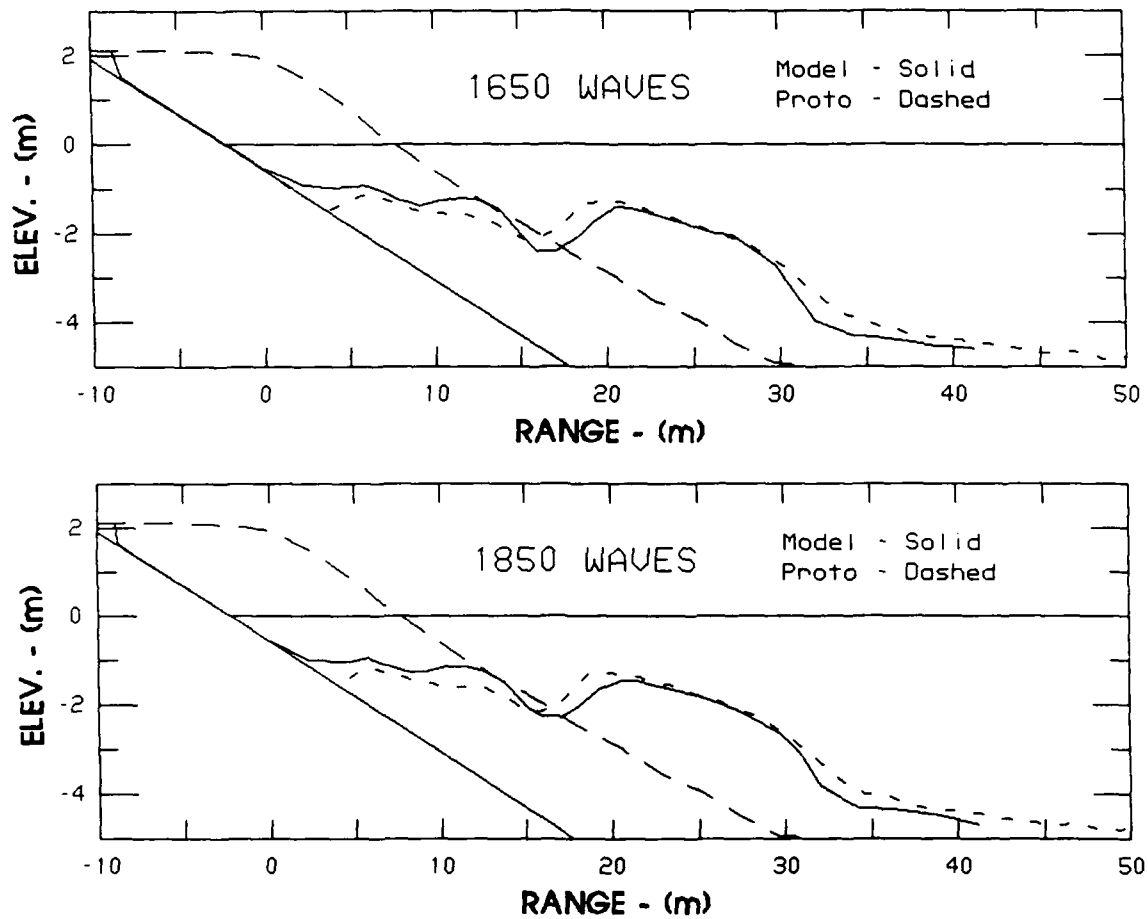


Figure E3. (Sheet 3 of 3)



## TEST T05 vs. PROTOTYPE

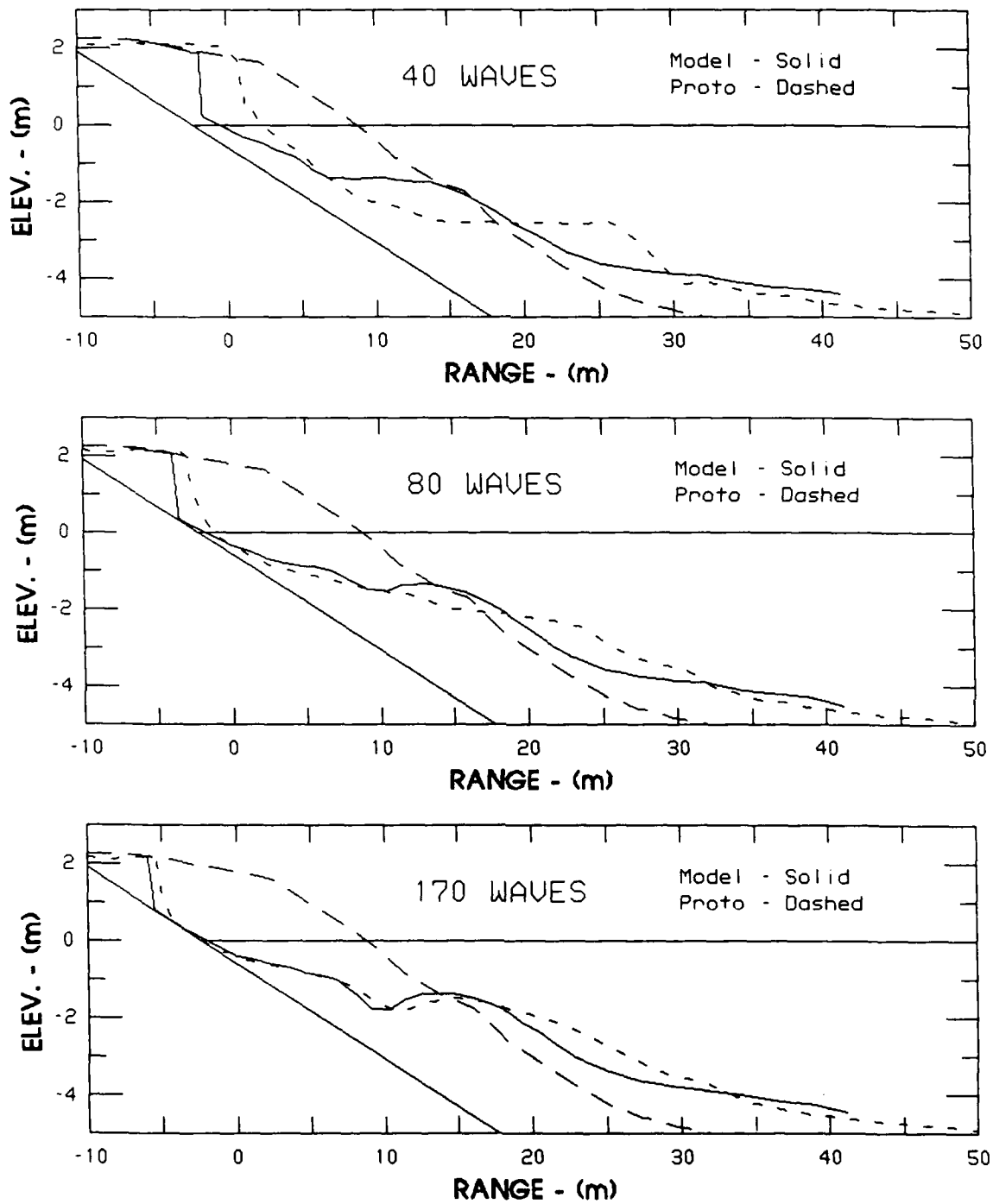


Figure E4. Test T05 versus prototype (Sheet 1 of 3)

## TEST T05 vs. PROTOTYPE

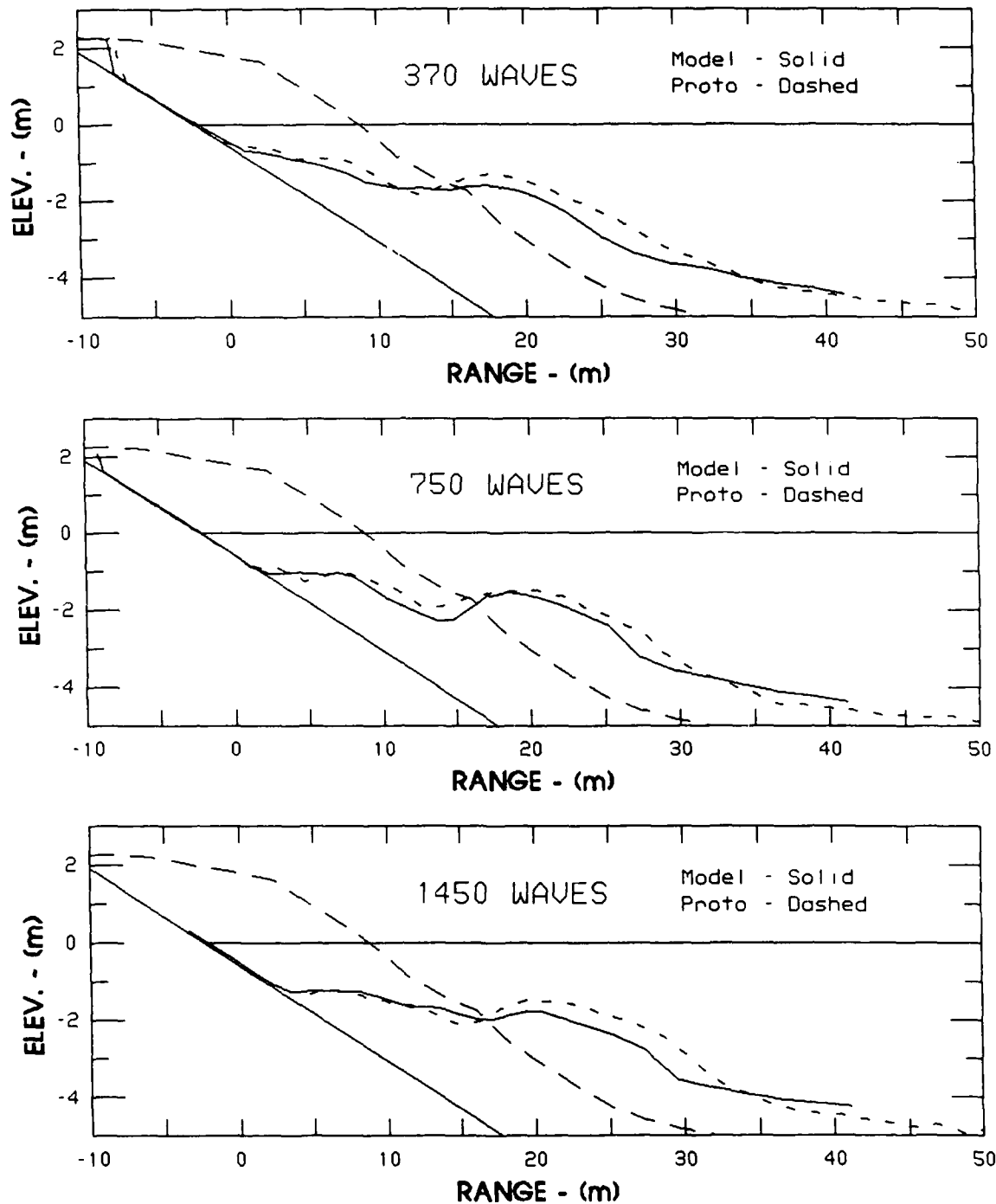


Figure E4. (Sheet 2 of 3)

## TEST T05 vs. PROTOTYPE

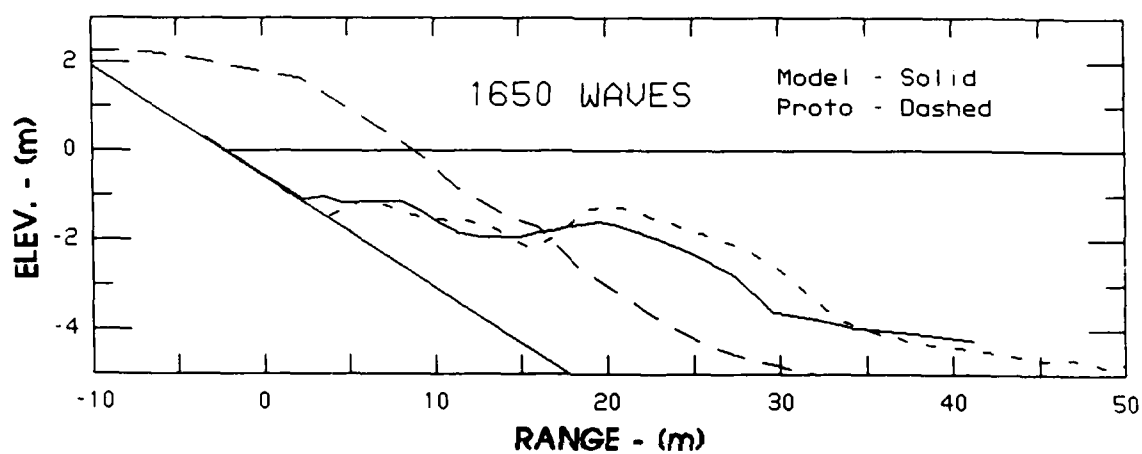


Figure E4. (Sheet 3 of 3)

## TEST T06 vs. PROTOTYPE

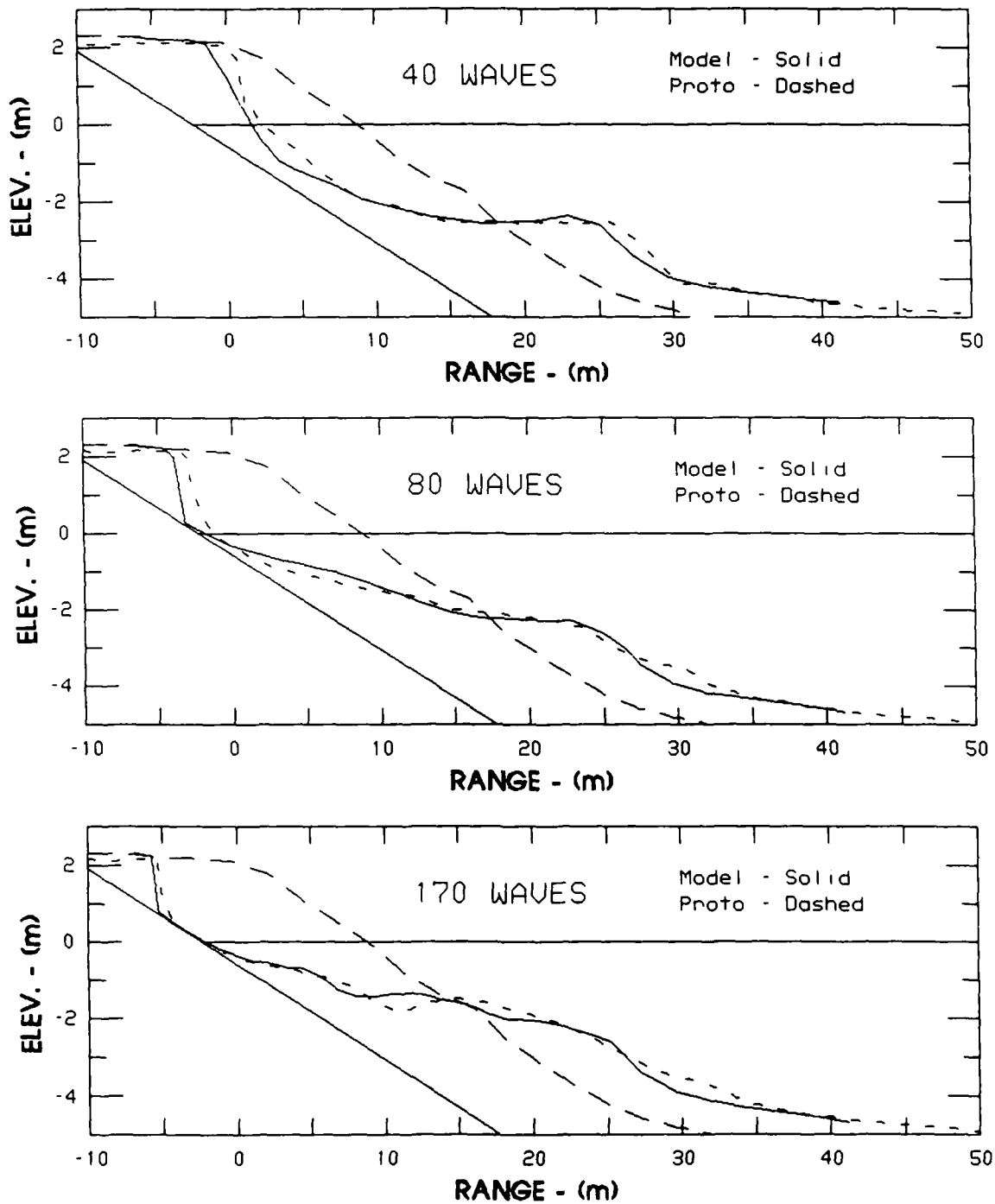


Figure E5. Test T06 versus prototype (Sheet 1 of 3)

## TEST T06 vs. PROTOTYPE

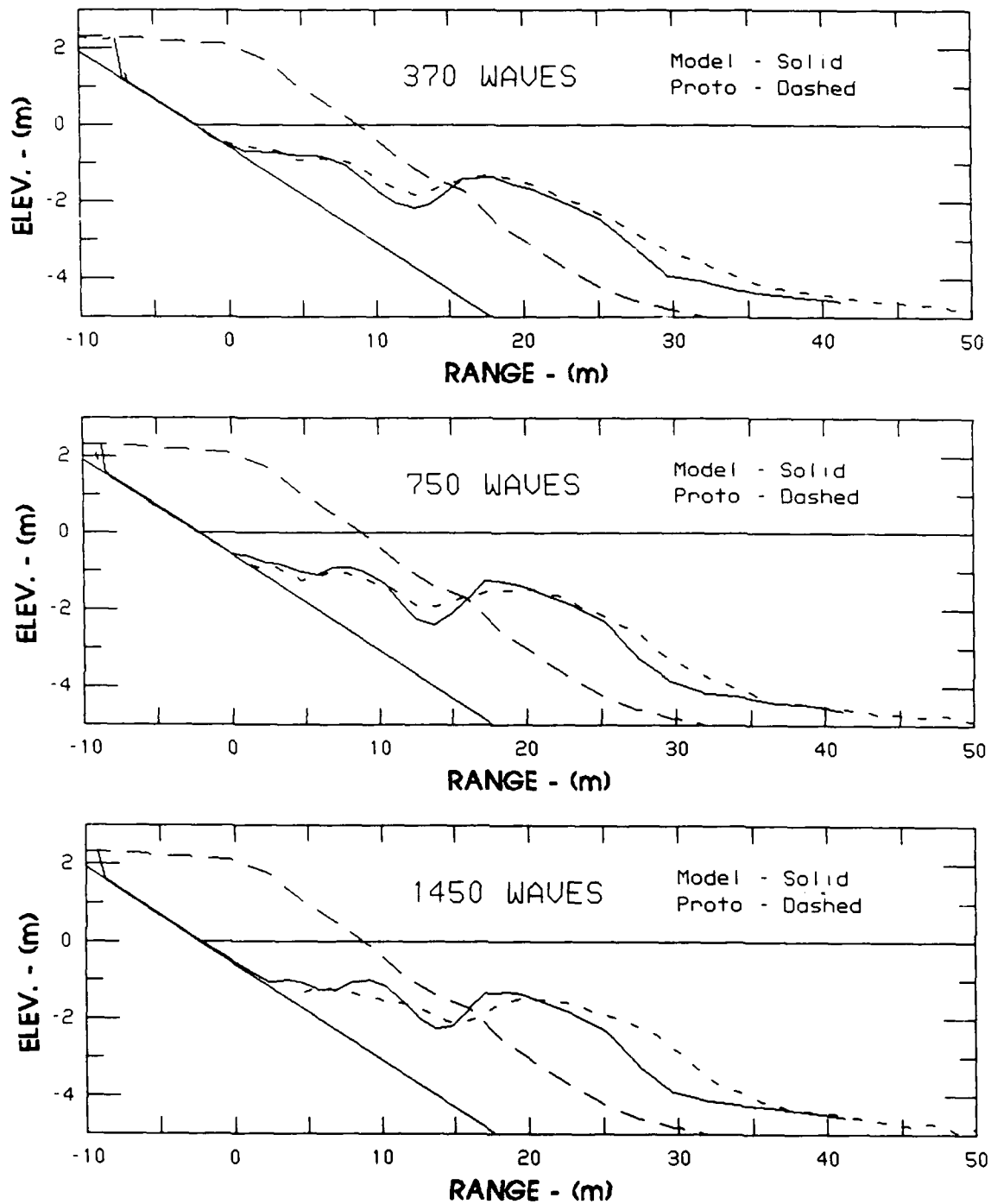


Figure E5. (Sheet 2 of 3)

## TEST T06 vs. PROTOTYPE

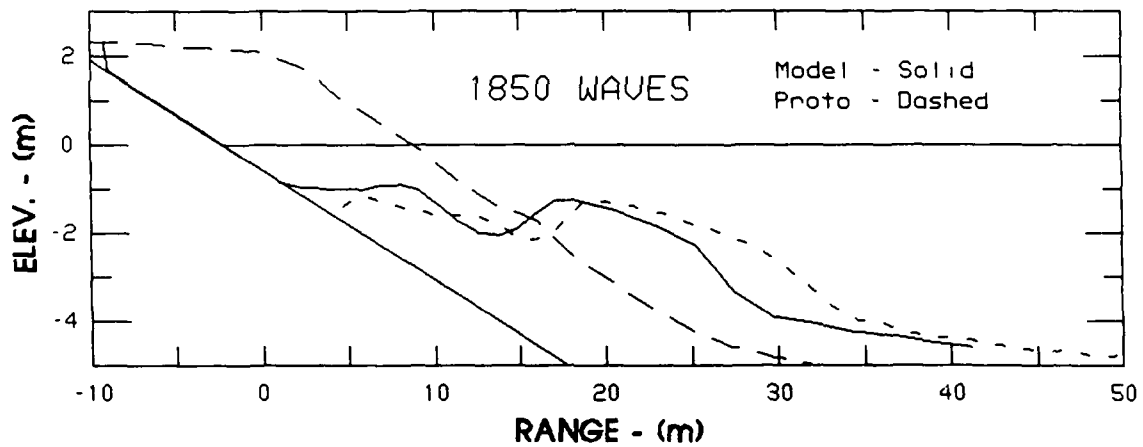
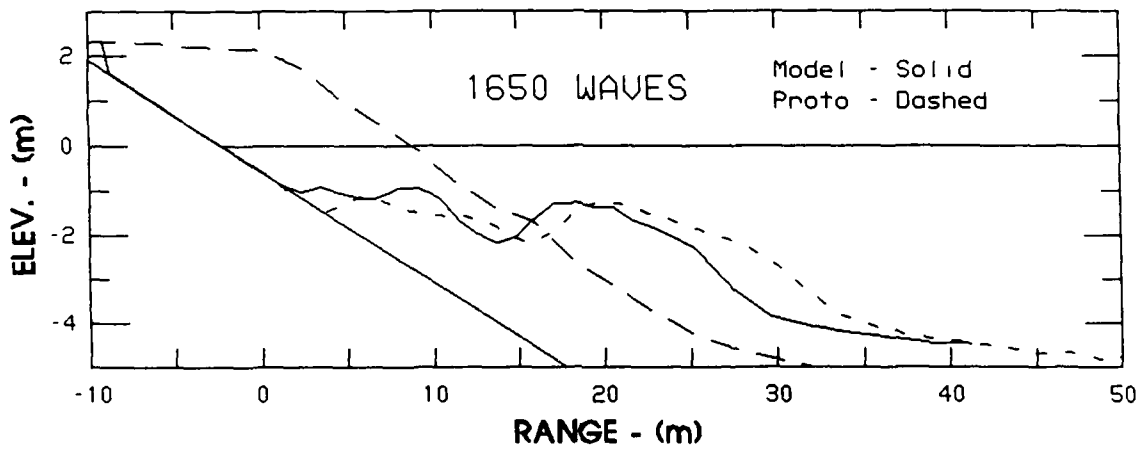


Figure E5. (Sheet 3 of 3)

## TEST T07 vs. PROTOTYPE

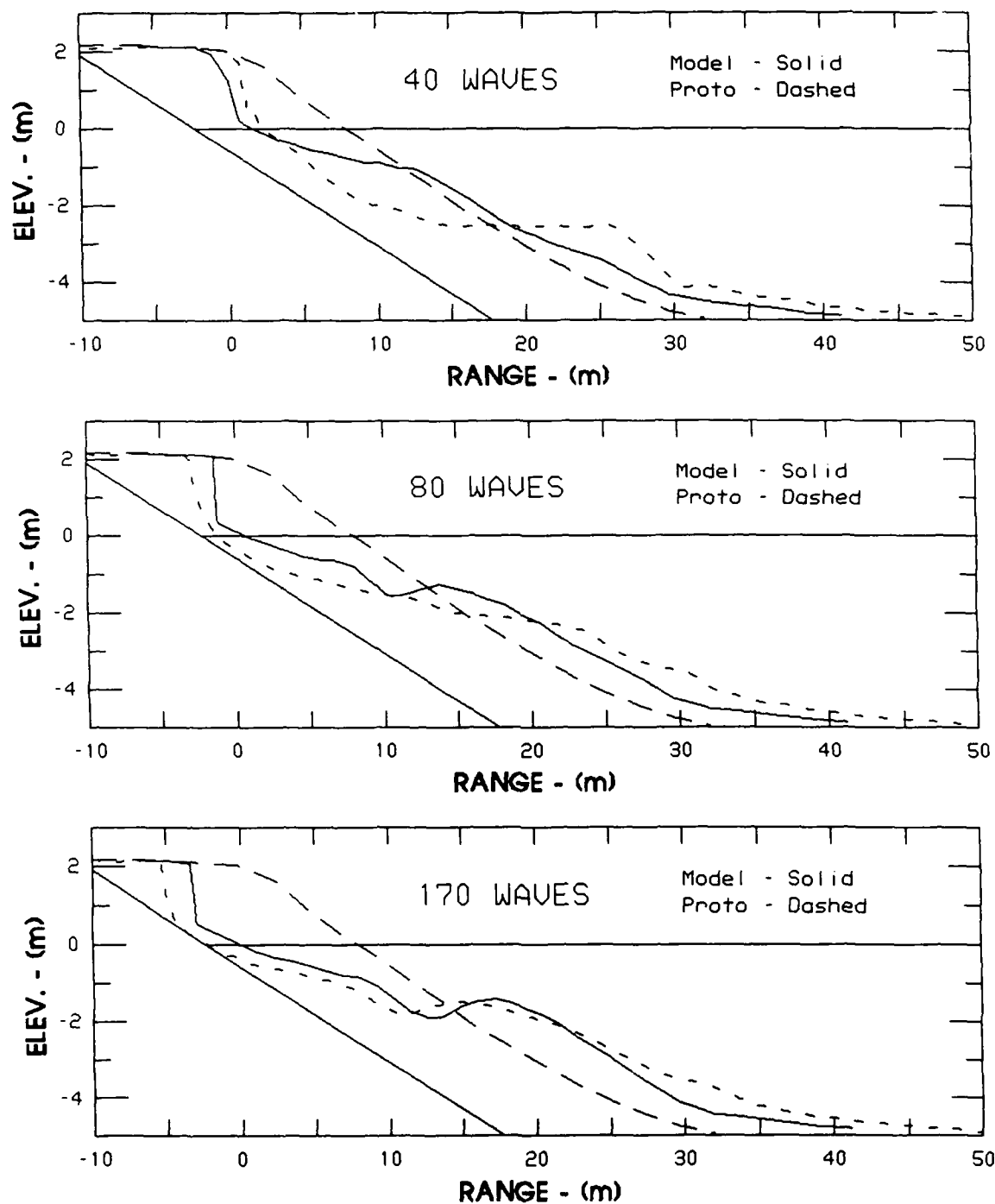


Figure E6. Test T07 versus prototype (Sheet 1 of 3)

## TEST T07 vs. PROTOTYPE

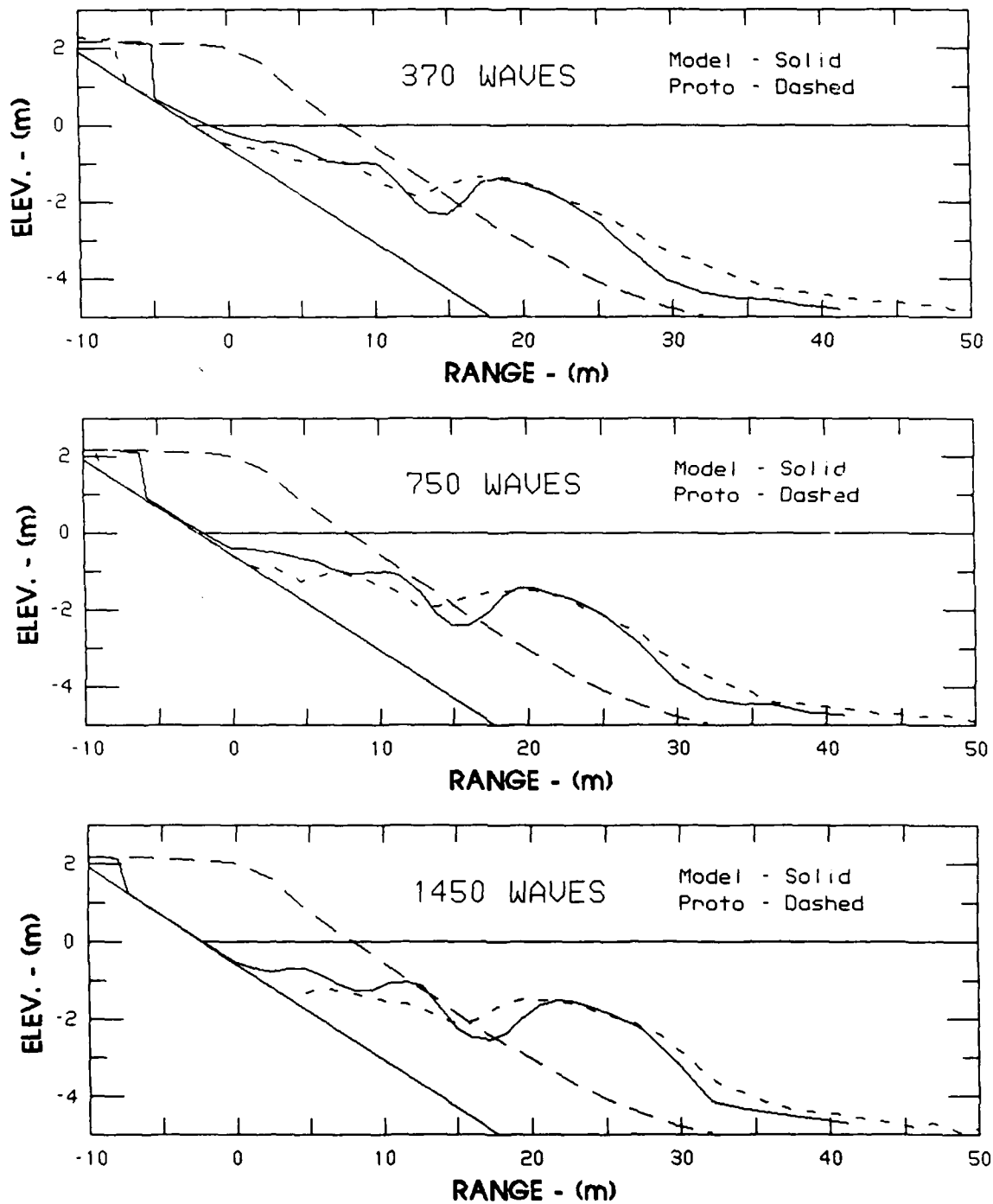


Figure E6. (Sheet 2 of 3)



## TEST T07 vs. PROTOTYPE

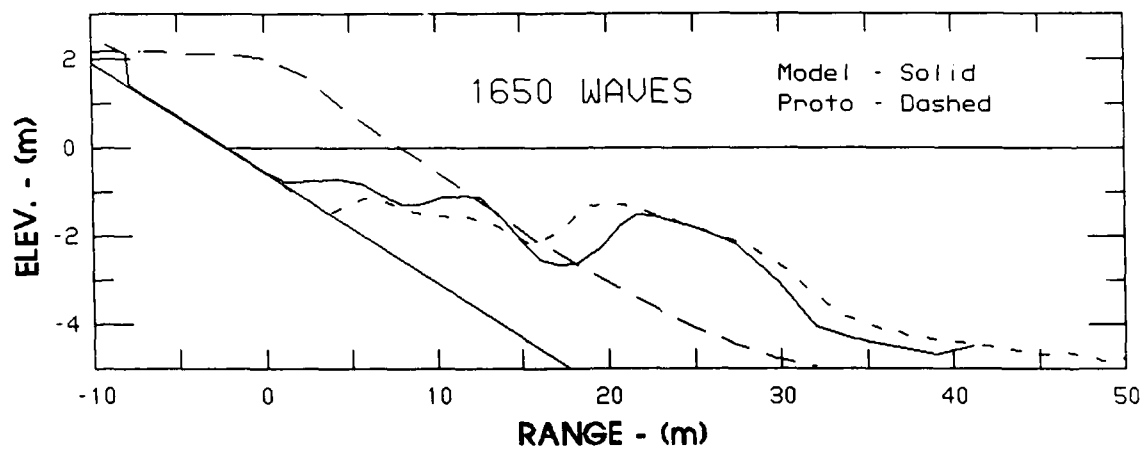


Figure E6. (Sheet 3 of 3)

## IRREGULAR TEST T14 vs. PROTOTYPE

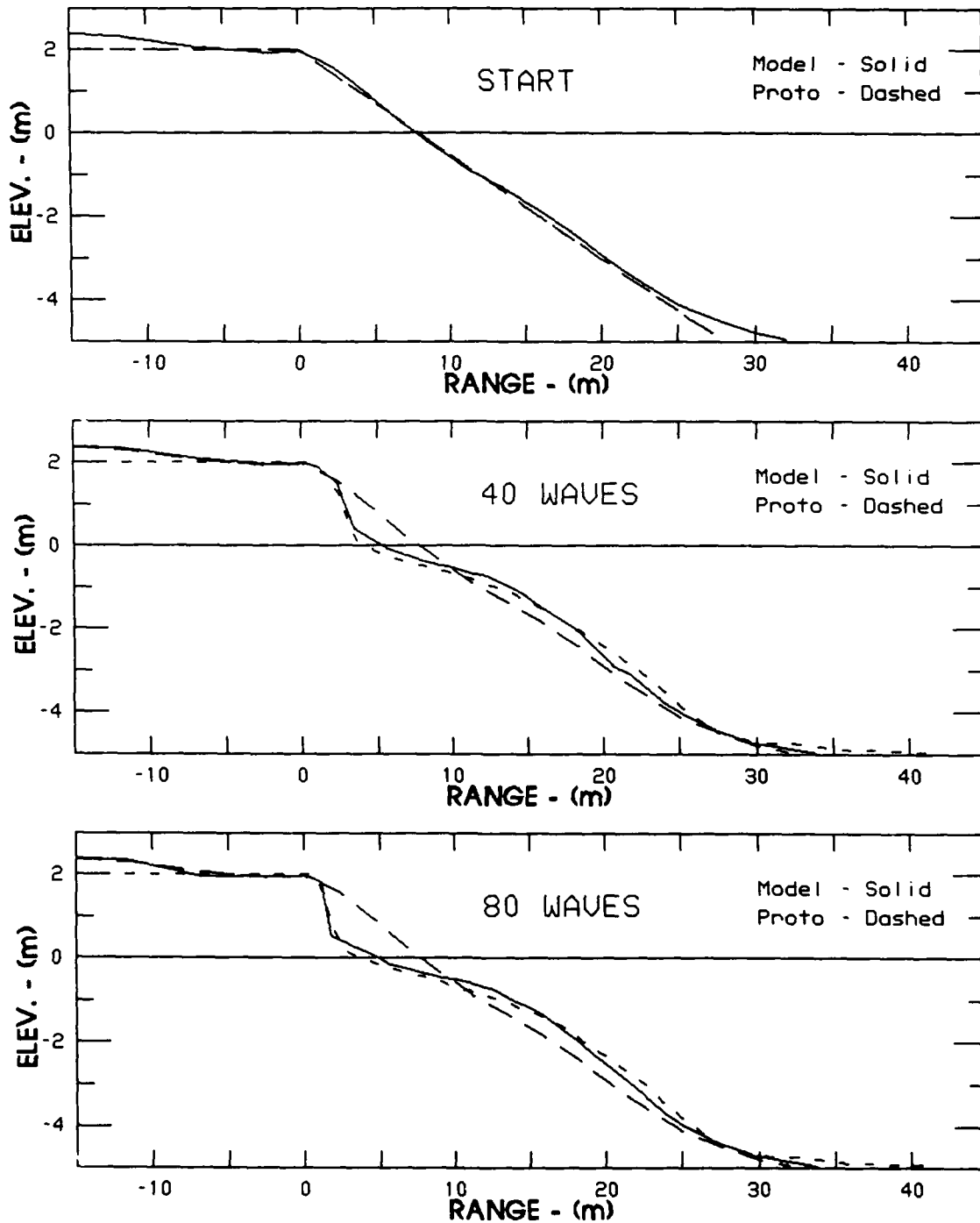


Figure E7. Irregular test T14 versus prototype (Sheet 1 of 6)

## IRREGULAR TEST T14 vs. PROTOTYPE

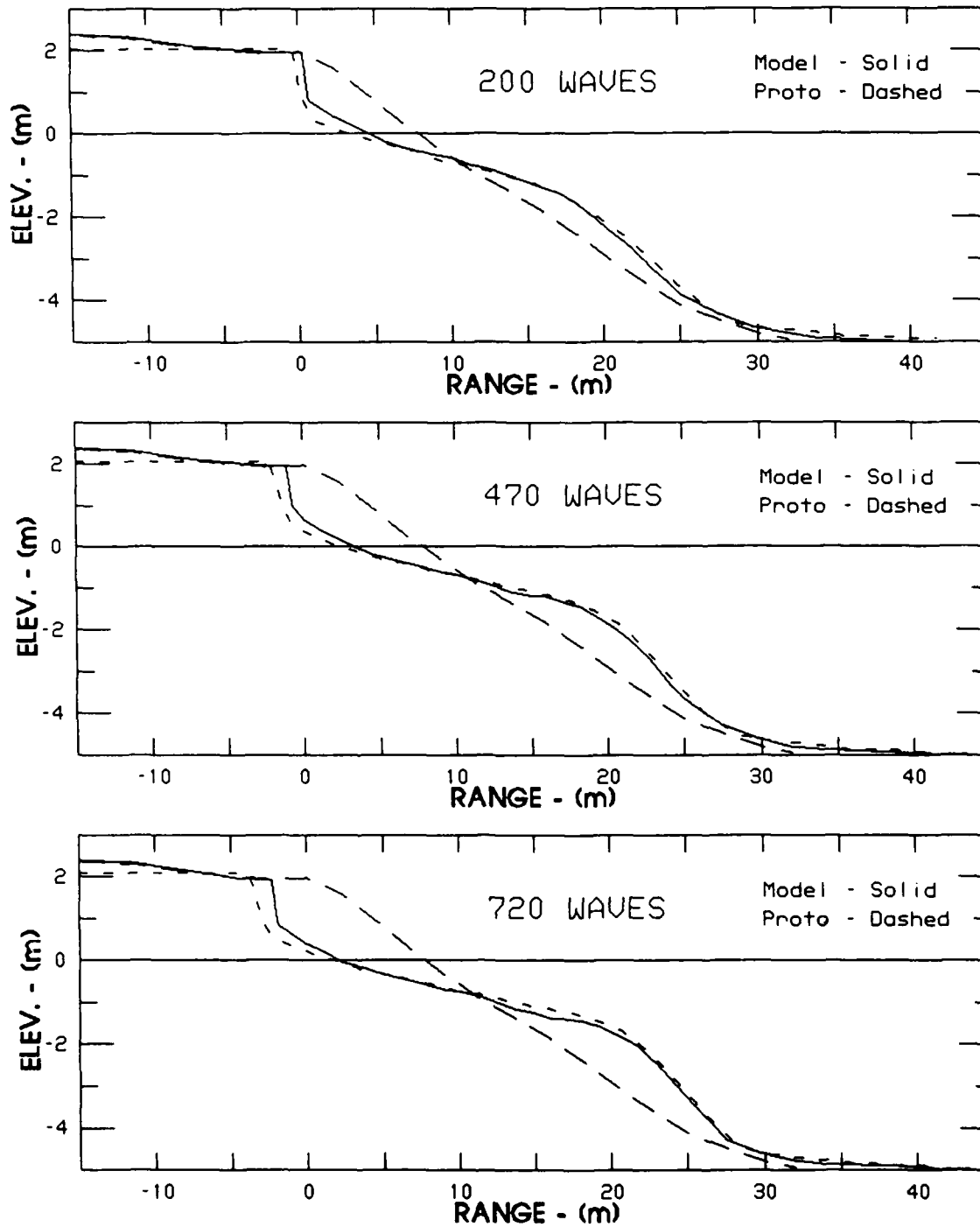


Figure E7. (Sheet 2 of 6)

## IRREGULAR TEST T14 vs. PROTOTYPE

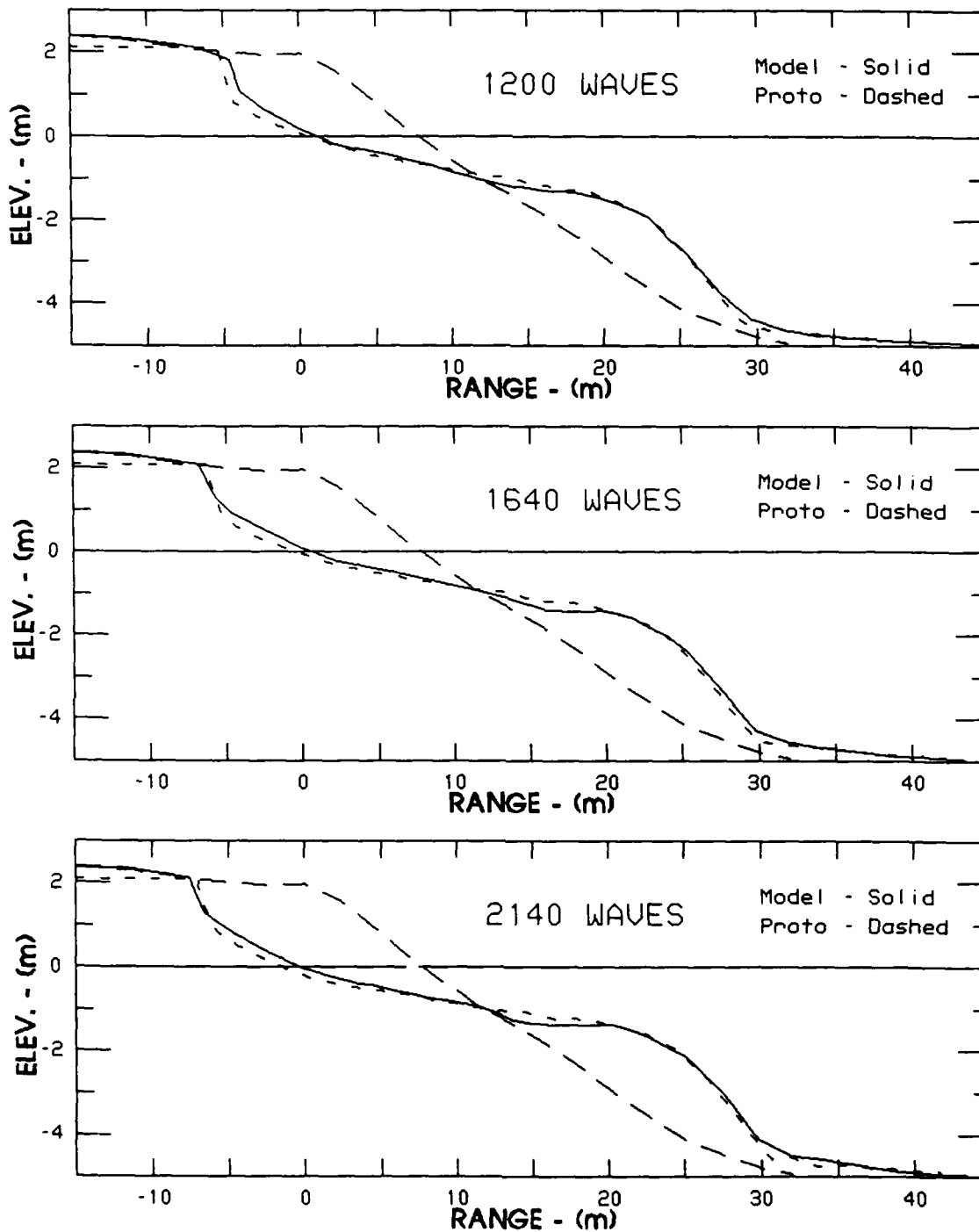


Figure E7. (Sheet 3 of 6)

## IRREGULAR TEST T14 vs. PROTOTYPE

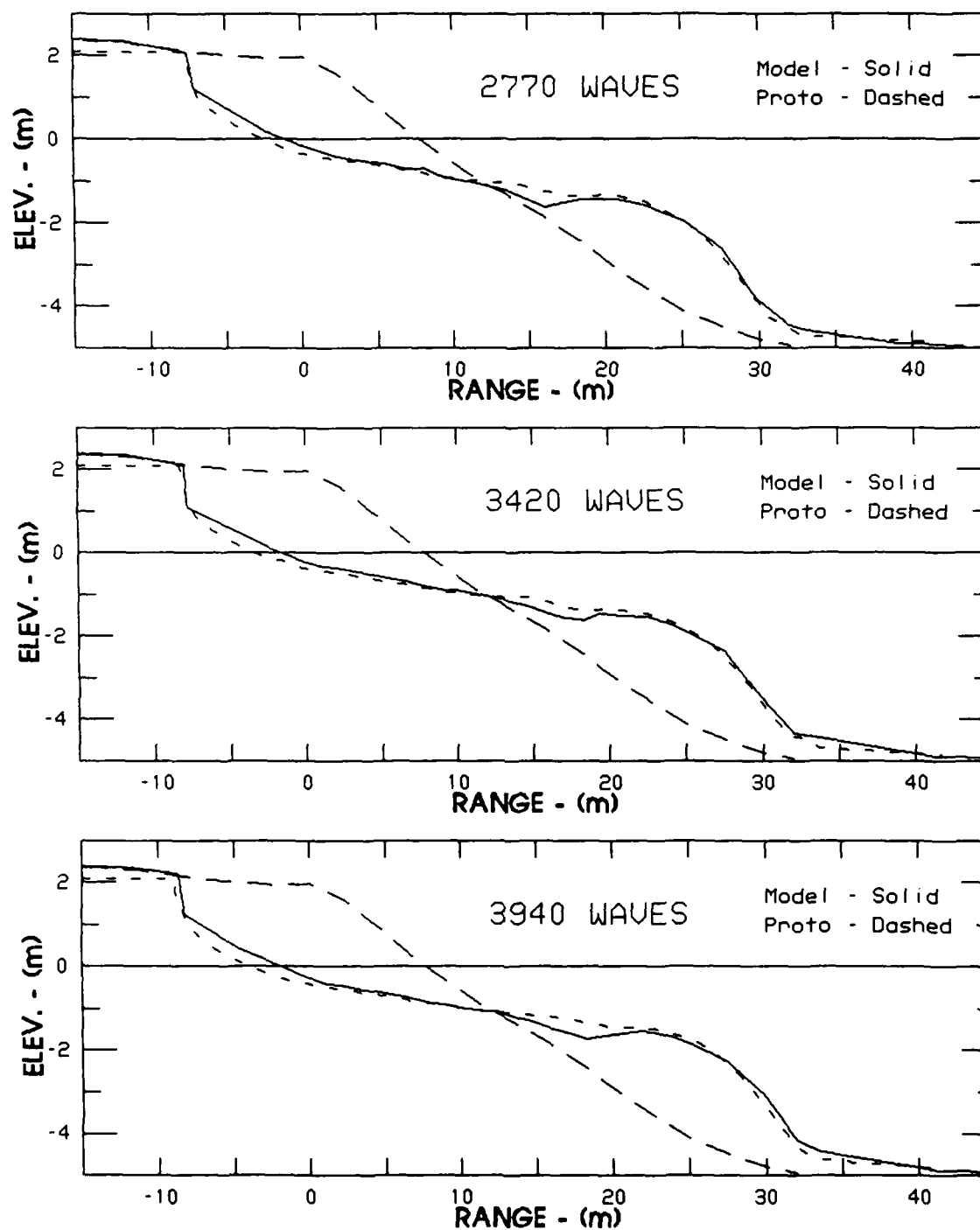


Figure E7. (Sheet 4 of 6)

## IRREGULAR TEST T14 vs. PROTOTYPE

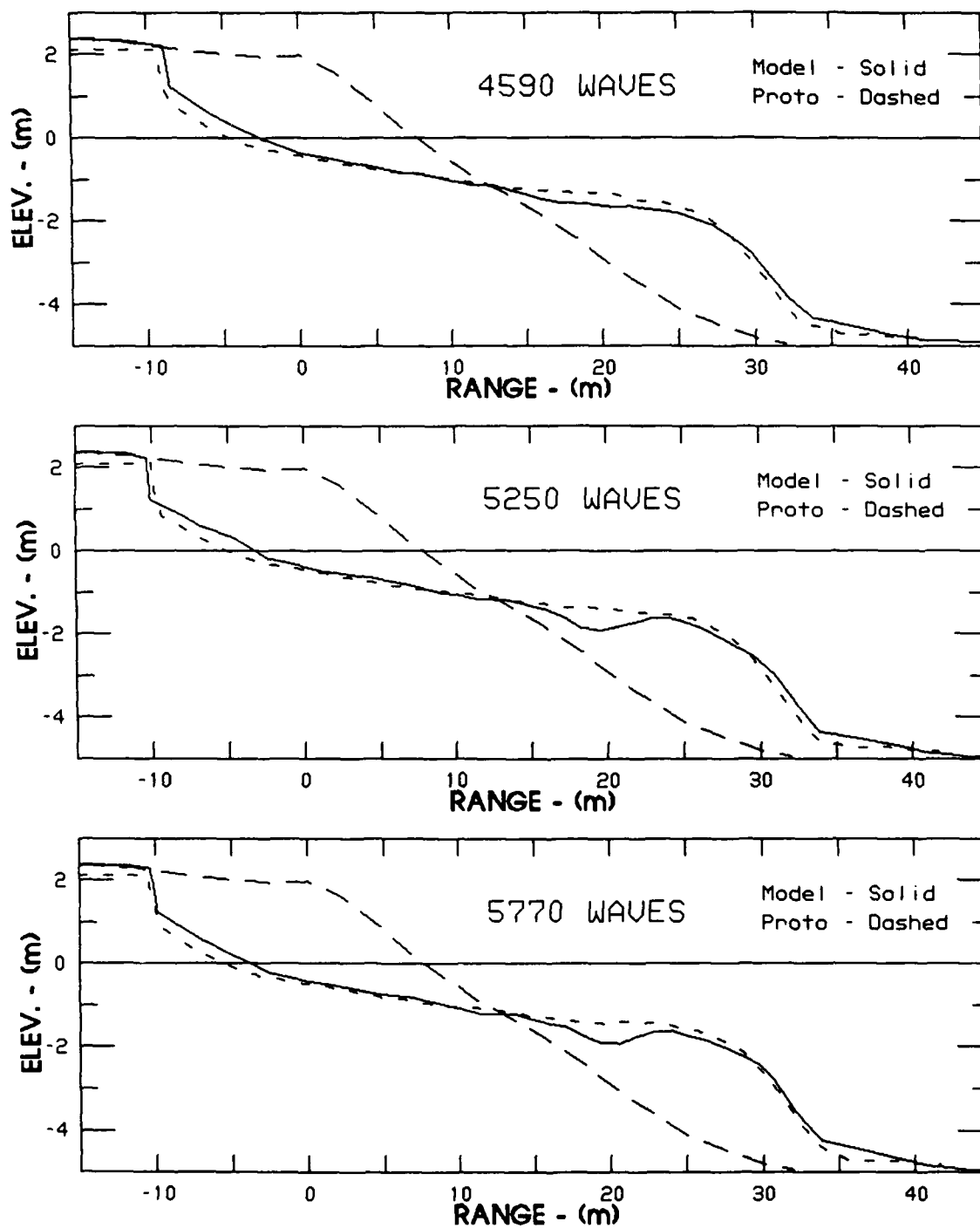


Figure E7. (Sheet 5 of 6)

## IRREGULAR TEST T14 vs. PROTOTYPE

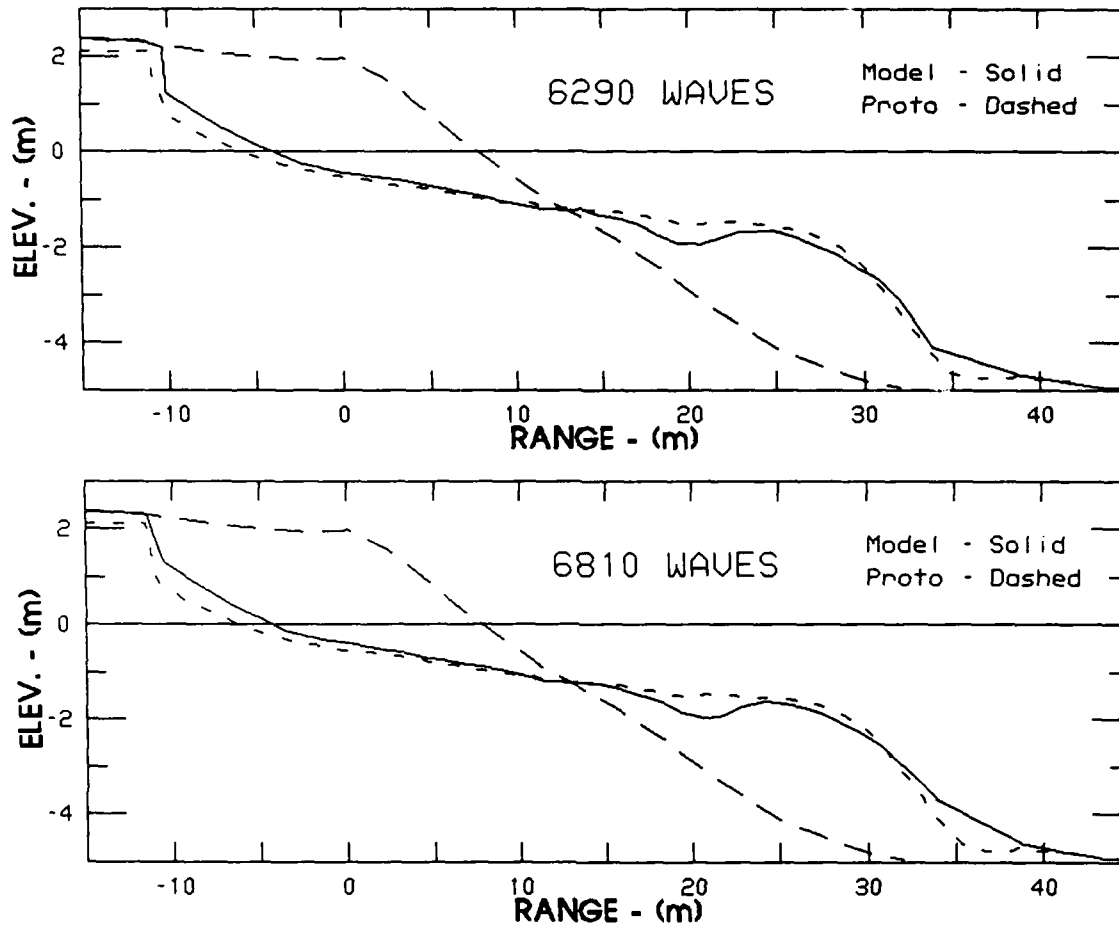


Figure E7. (Sheet 6 of 6)

## REPEATABILITY TEST

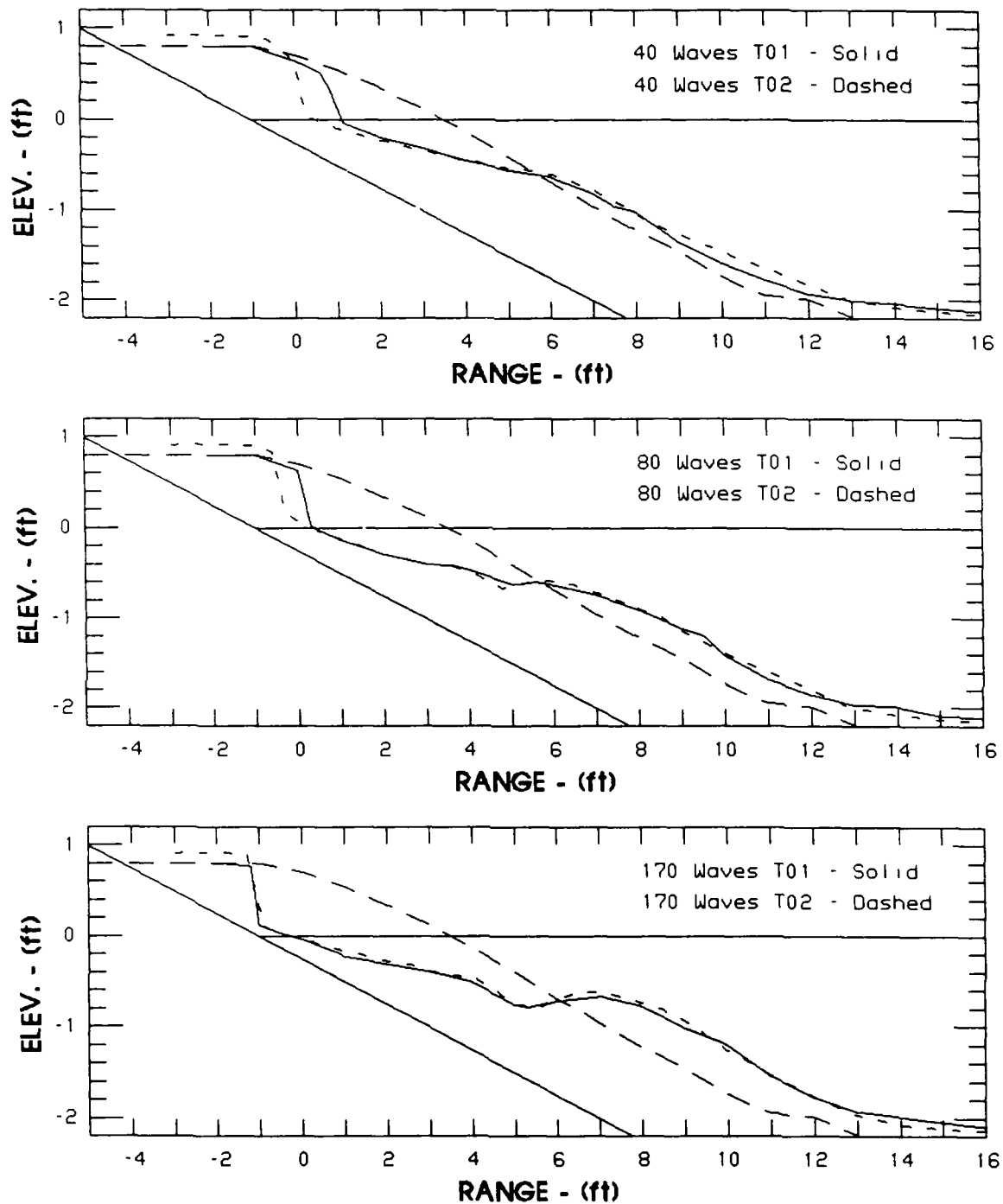


Figure E8. Repeatability test, T01 versus T02 (Sheet 1 of 3)



## REPEATABILITY TEST

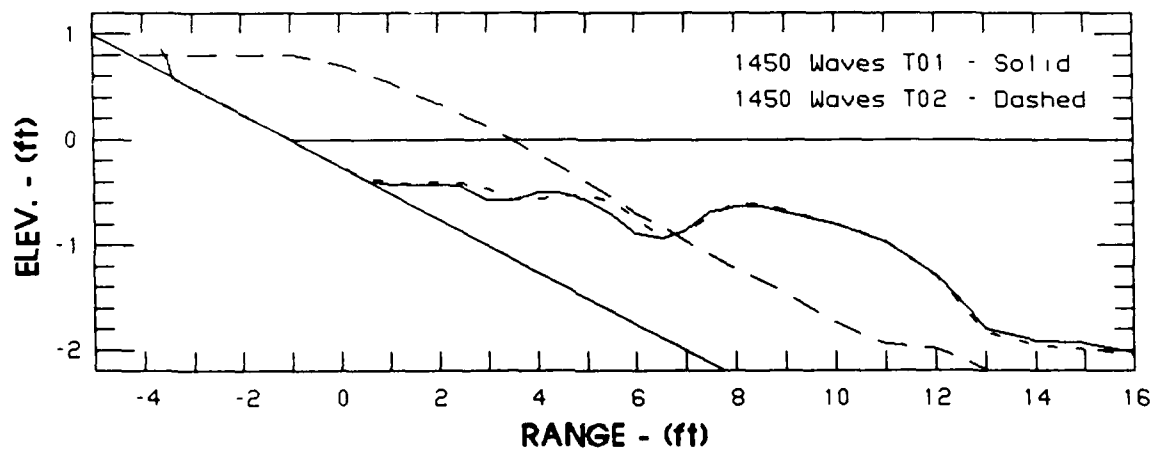
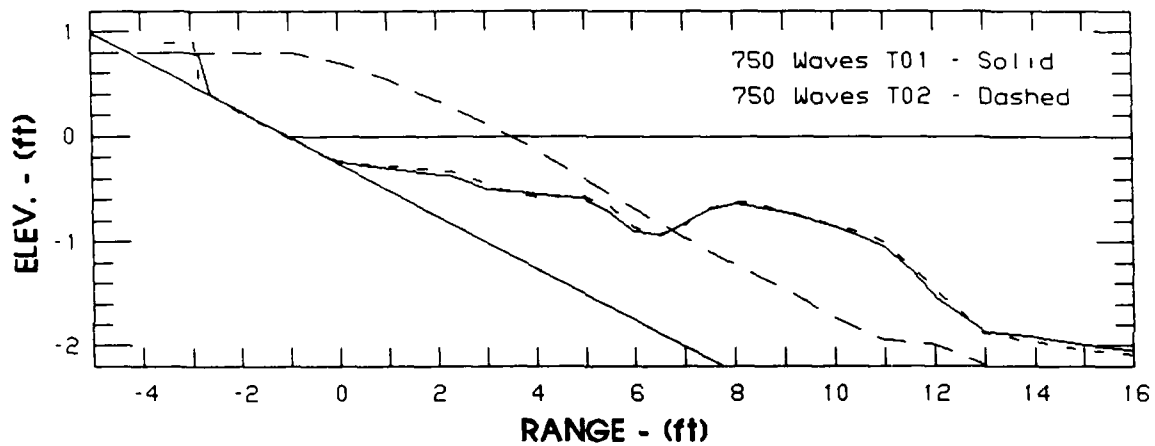
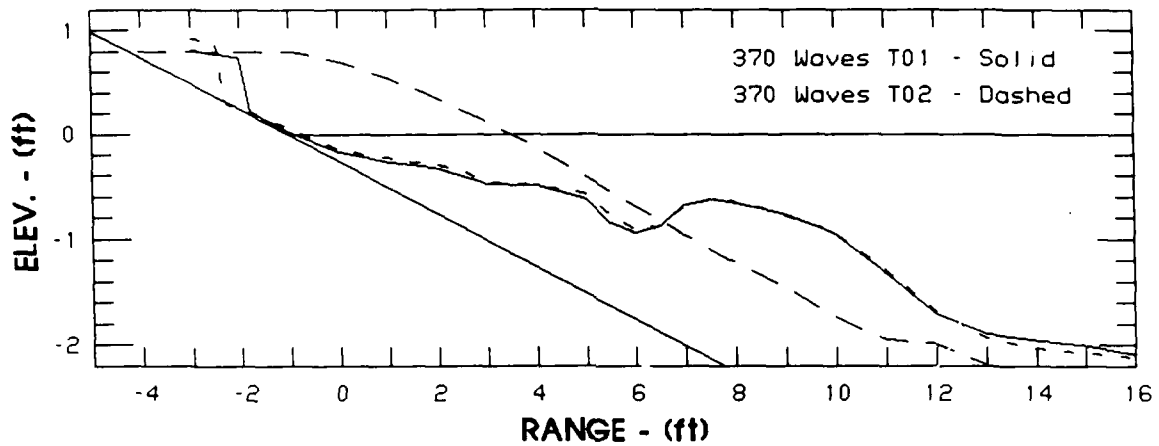


Figure E8. (Sheet 2 of 3)

## REPEATABILITY TEST

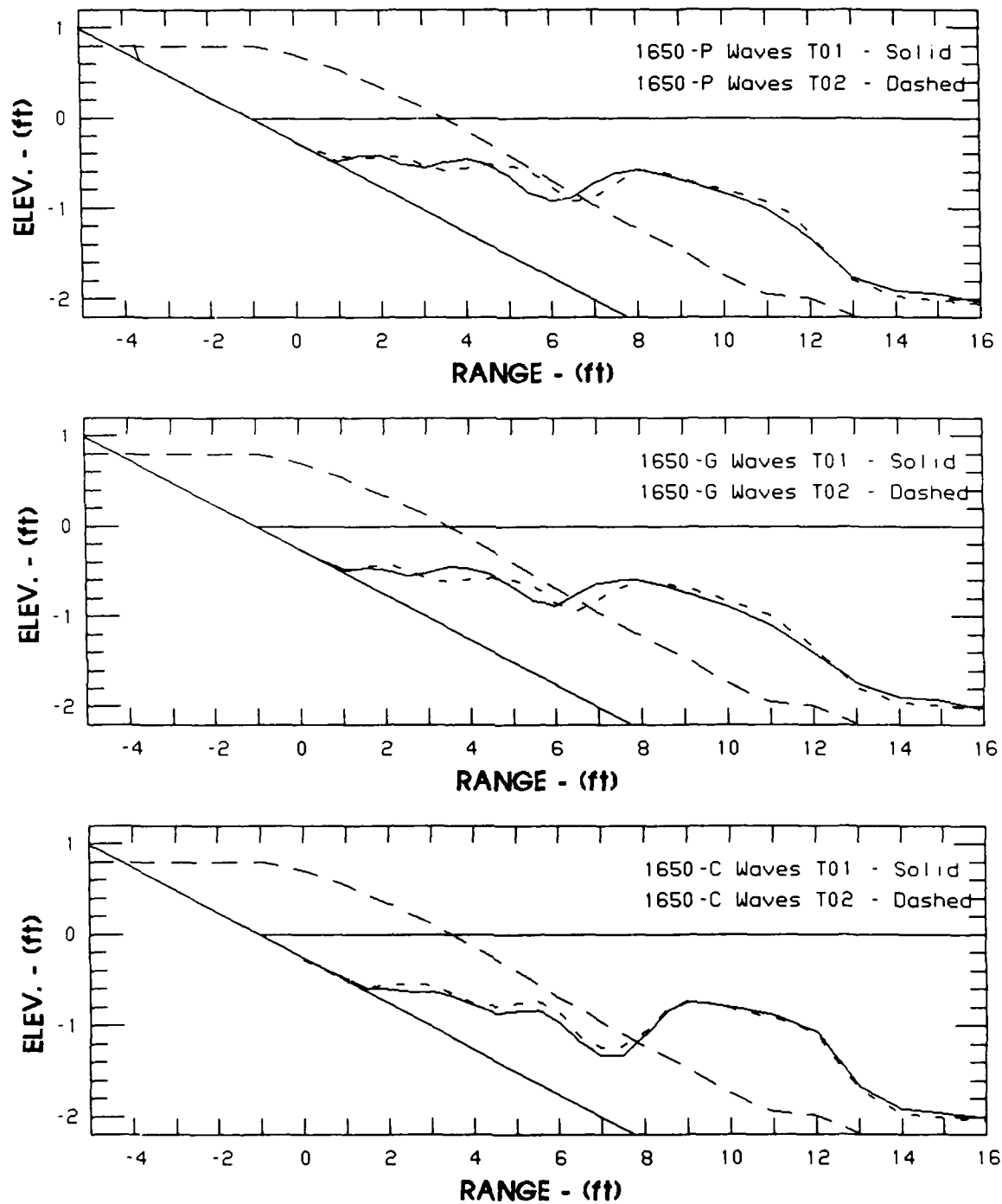


Figure E8. (Sheet 3 of 3)

# WAVE HEIGHT PERTURBATION

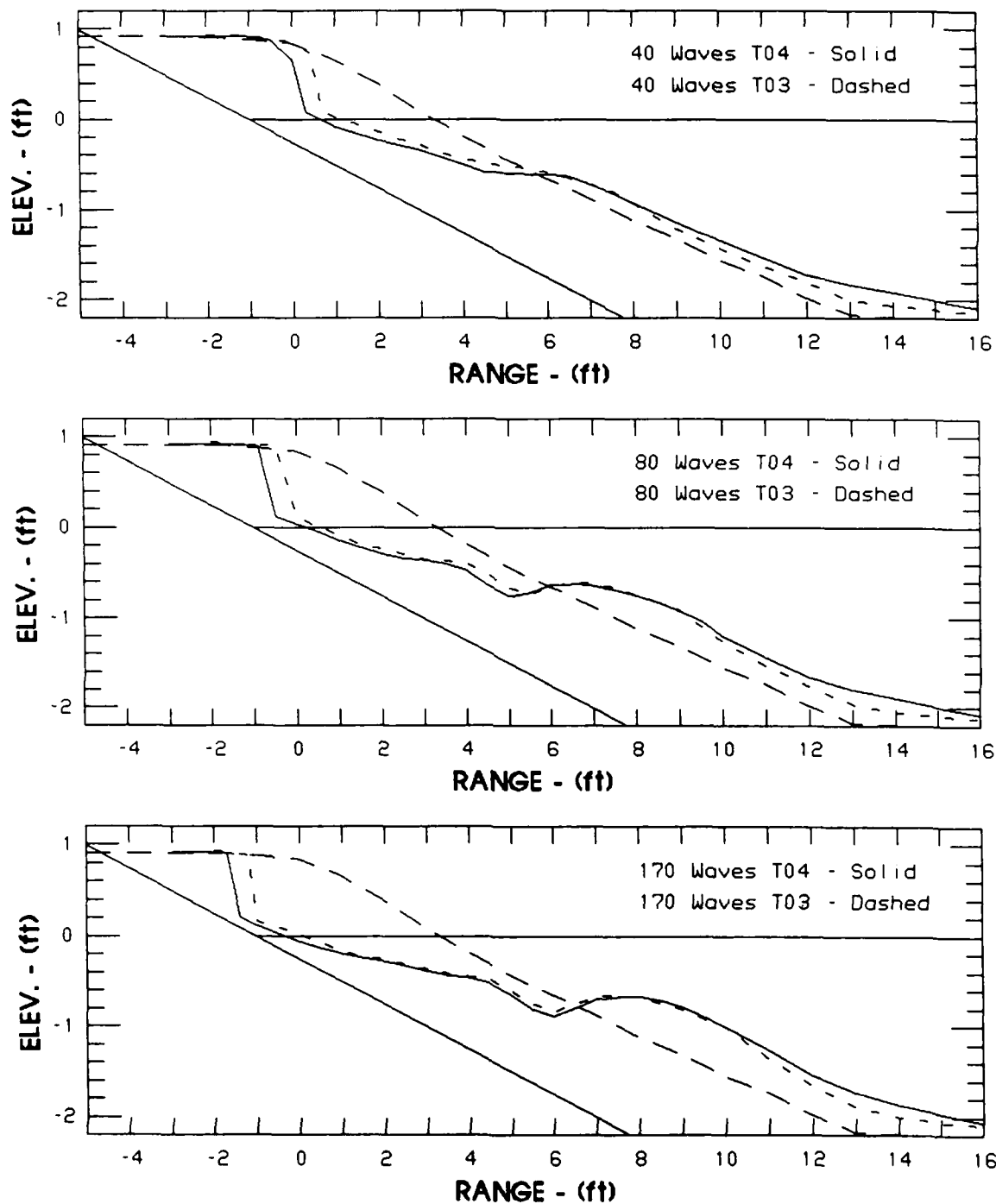


Figure E9. Wave height perturbation, T04 versus T03  
(Sheet 1 of 4)

## WAVE HEIGHT PERTURBATION

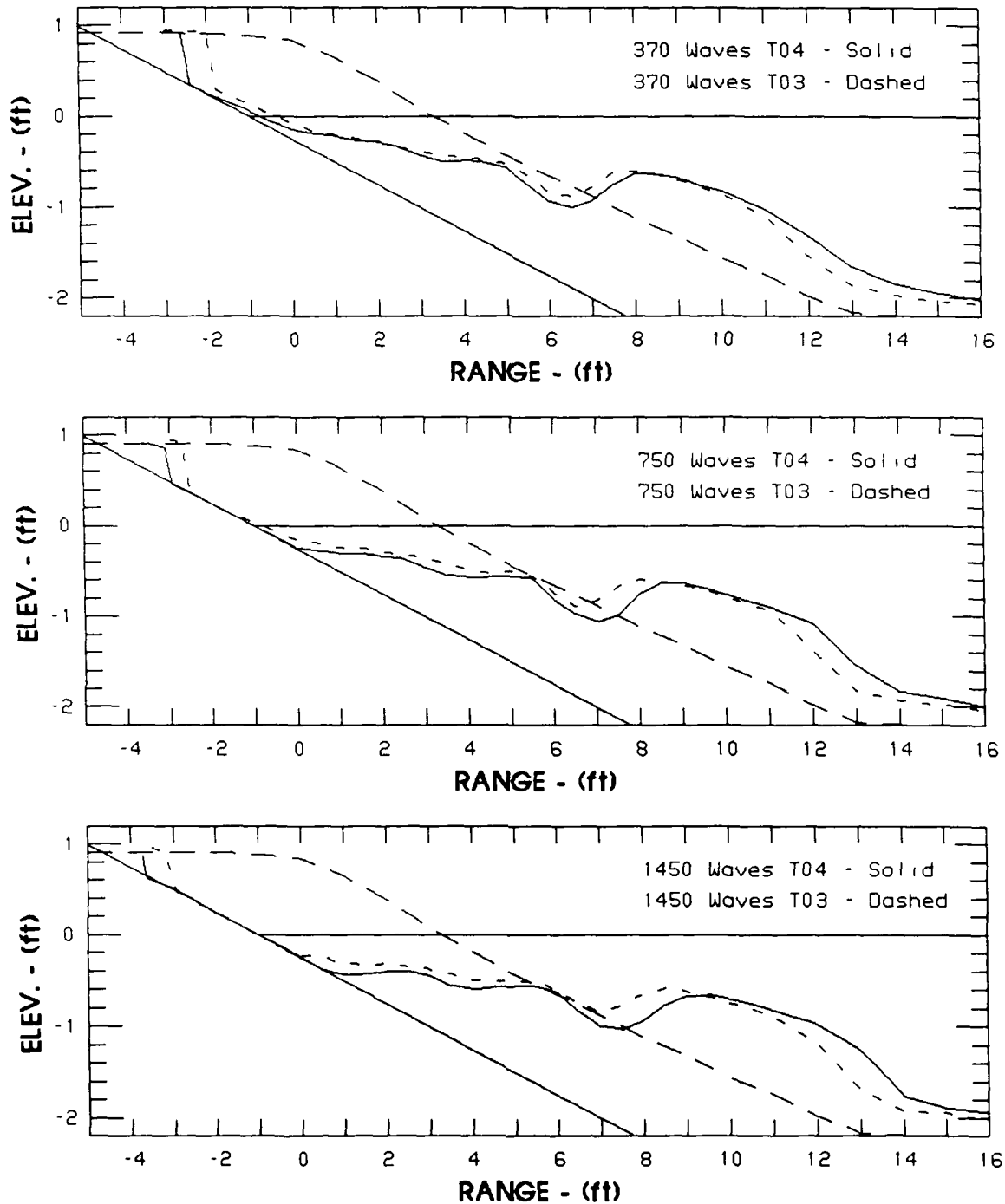


Figure E9. (Sheet 2 of 4)

## WAVE HEIGHT PERTURBATION

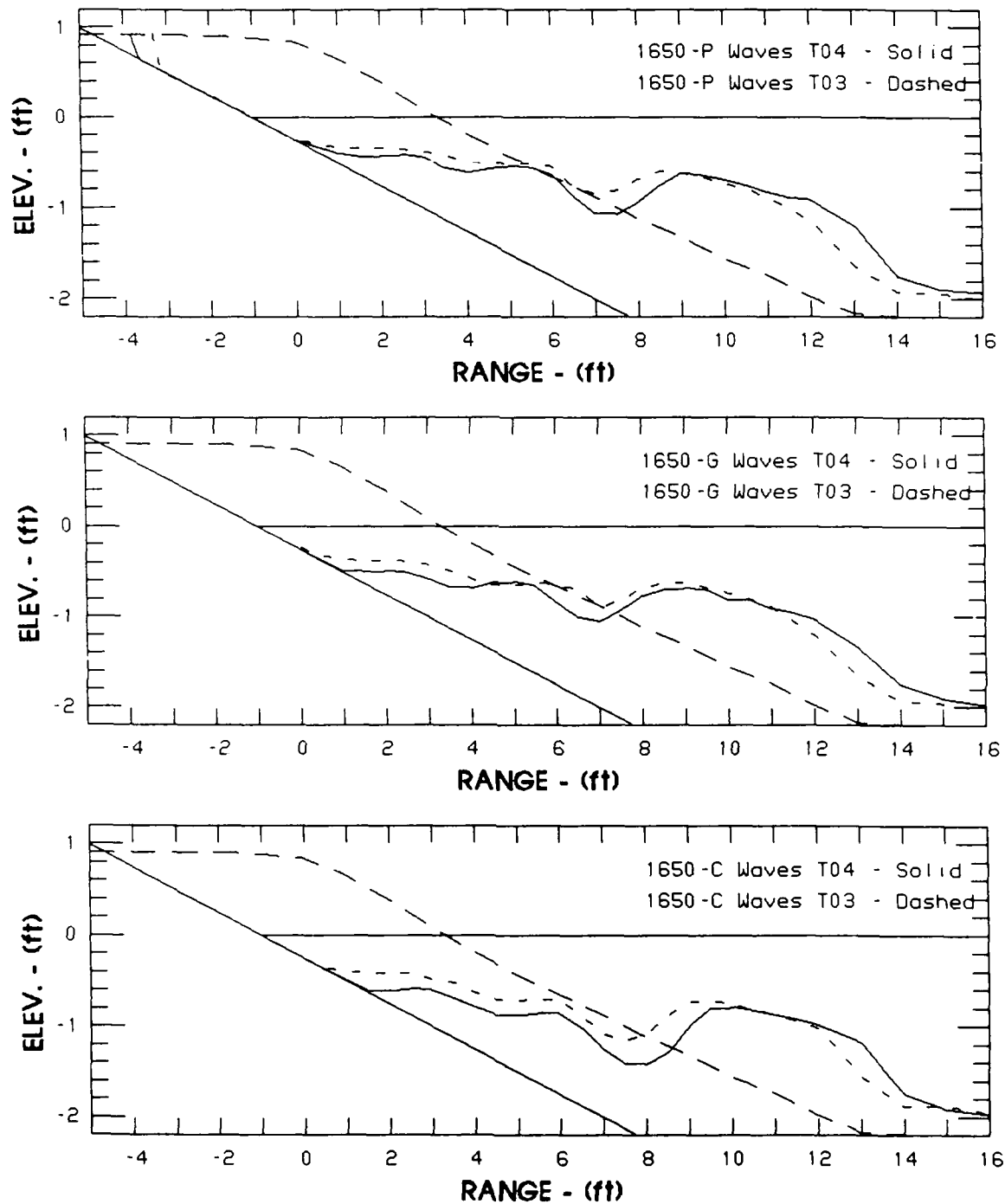


Figure E9. (Sheet 3 of 4)

## WAVE HEIGHT PERTURBATION

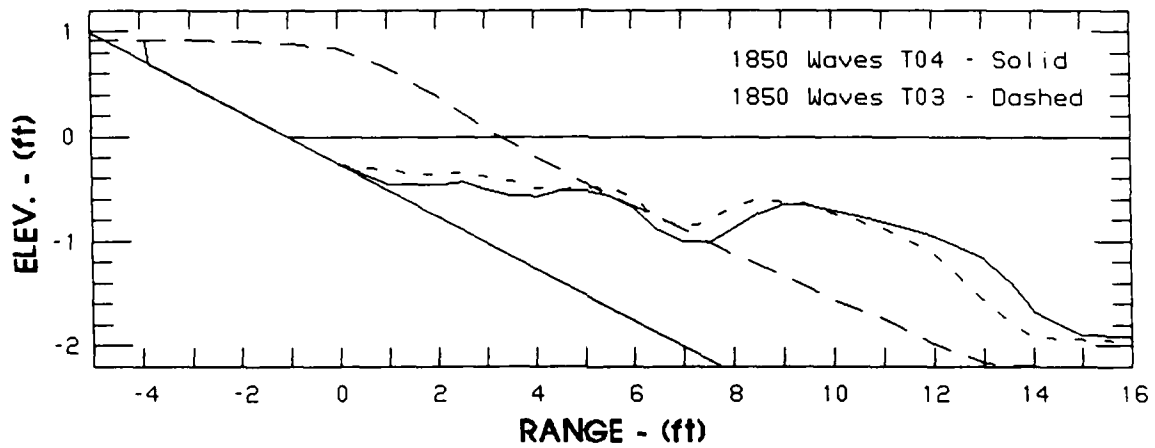


Figure E9. (Sheet 4 of 4)

# WAVE PERIOD PERTURBATION

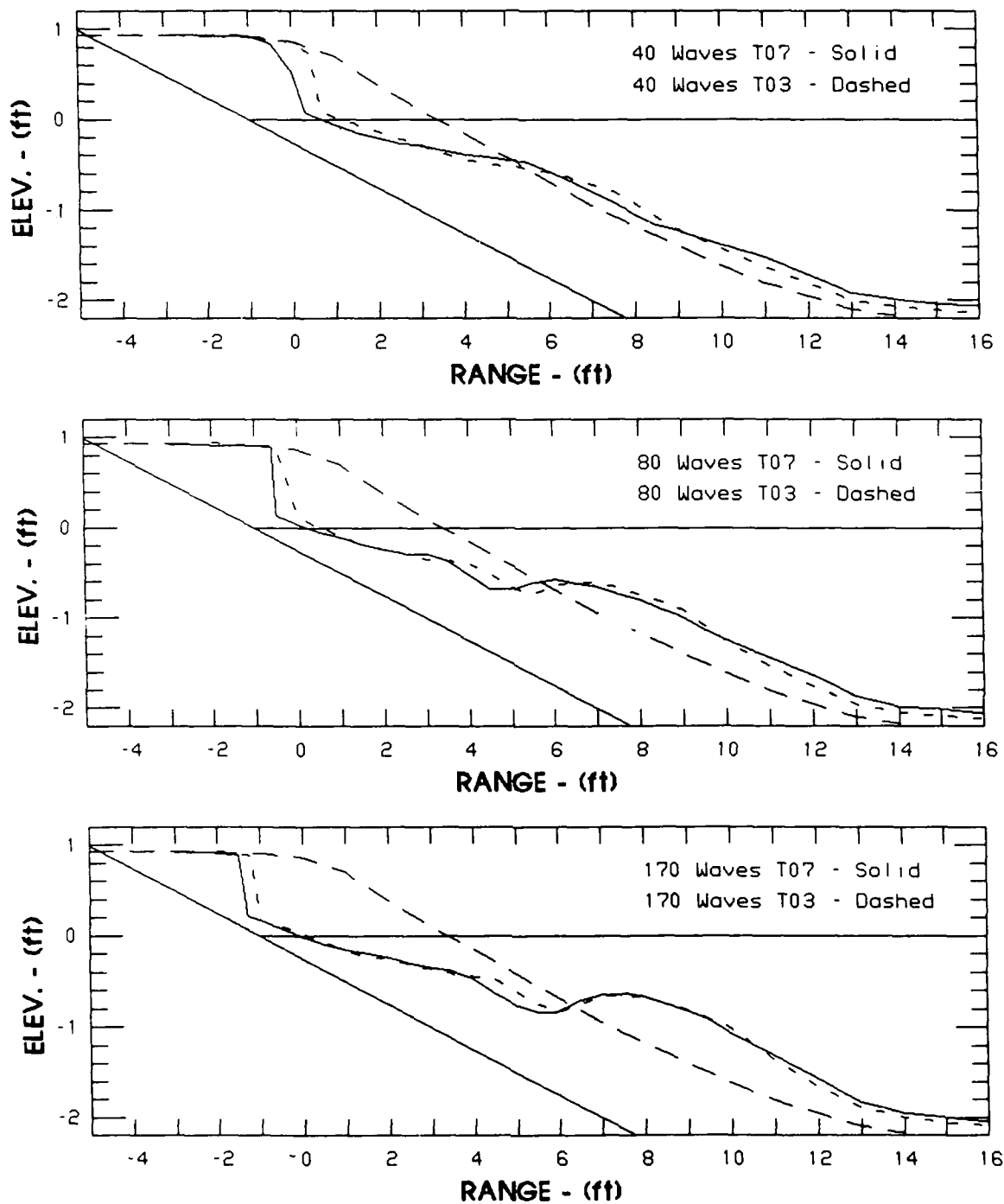


Figure E10. Wave period perturbation, T07 versus T03  
(Sheet 1 of 3)

## WAVE PERIOD PERTURBATION

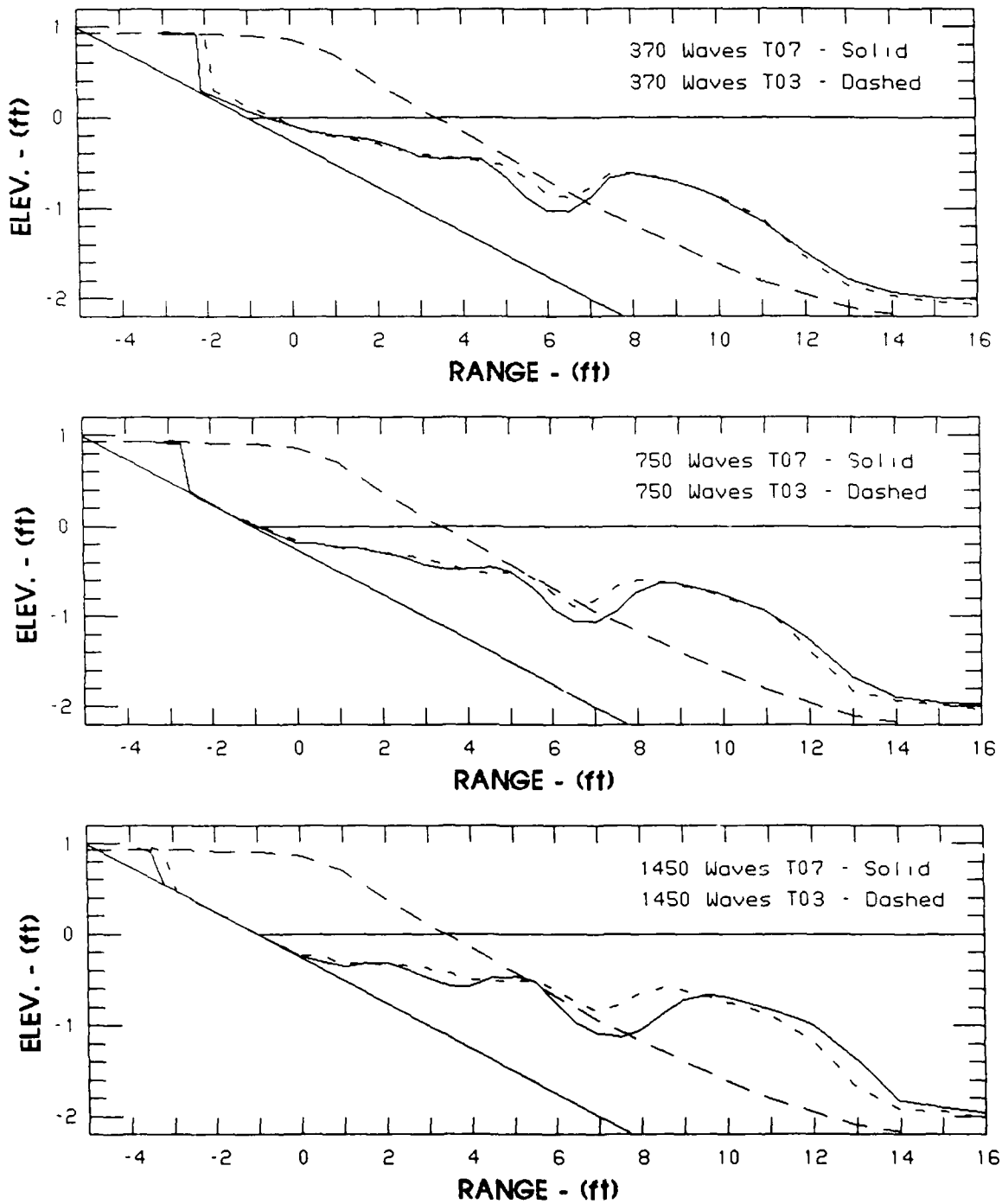


Figure E10. (Sheet 2 of 3)



## WAVE PERIOD PERTURBATION

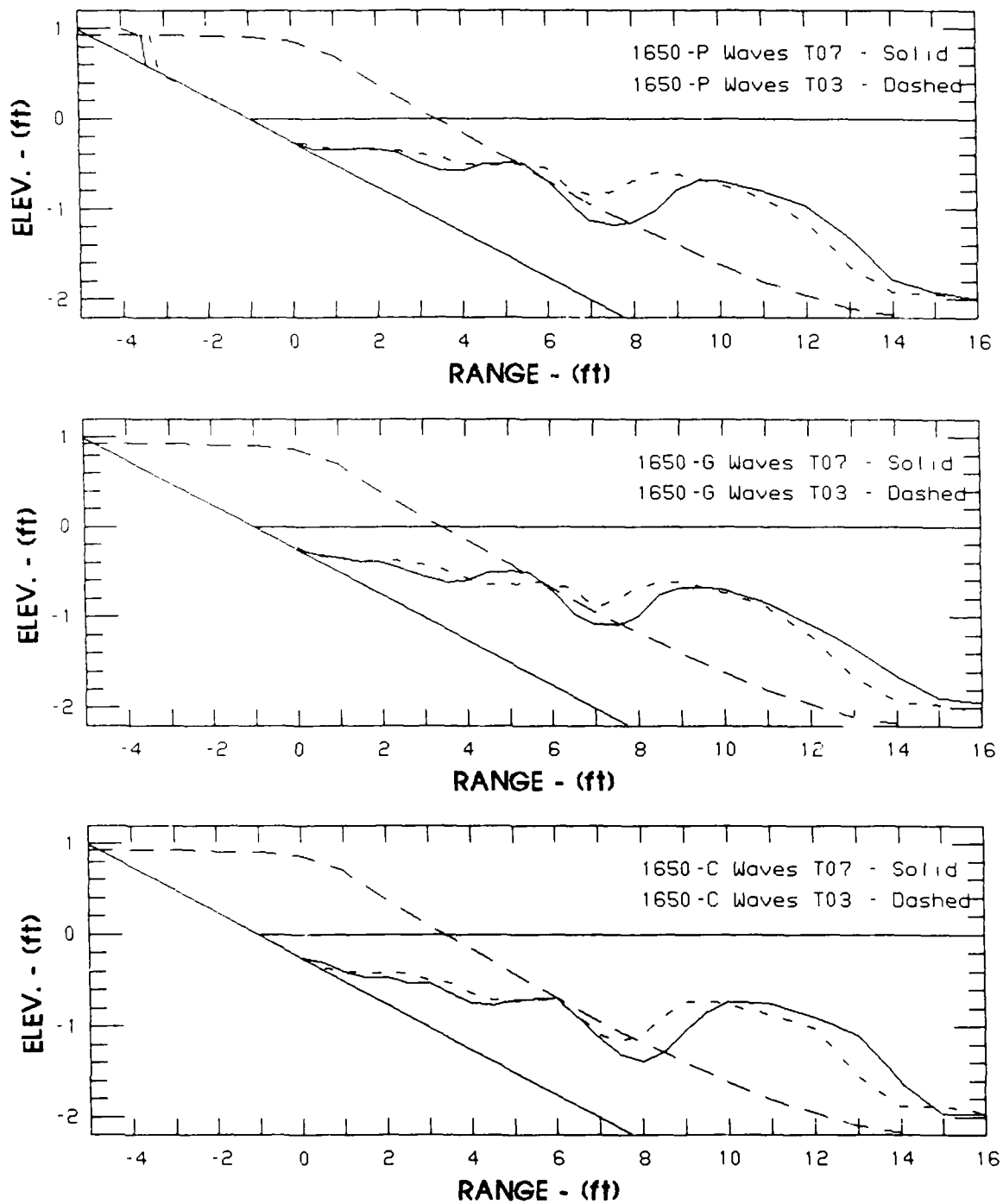


Figure E10. (Sheet 3 of 3)

## EQUAL H/wT PARAMETERS

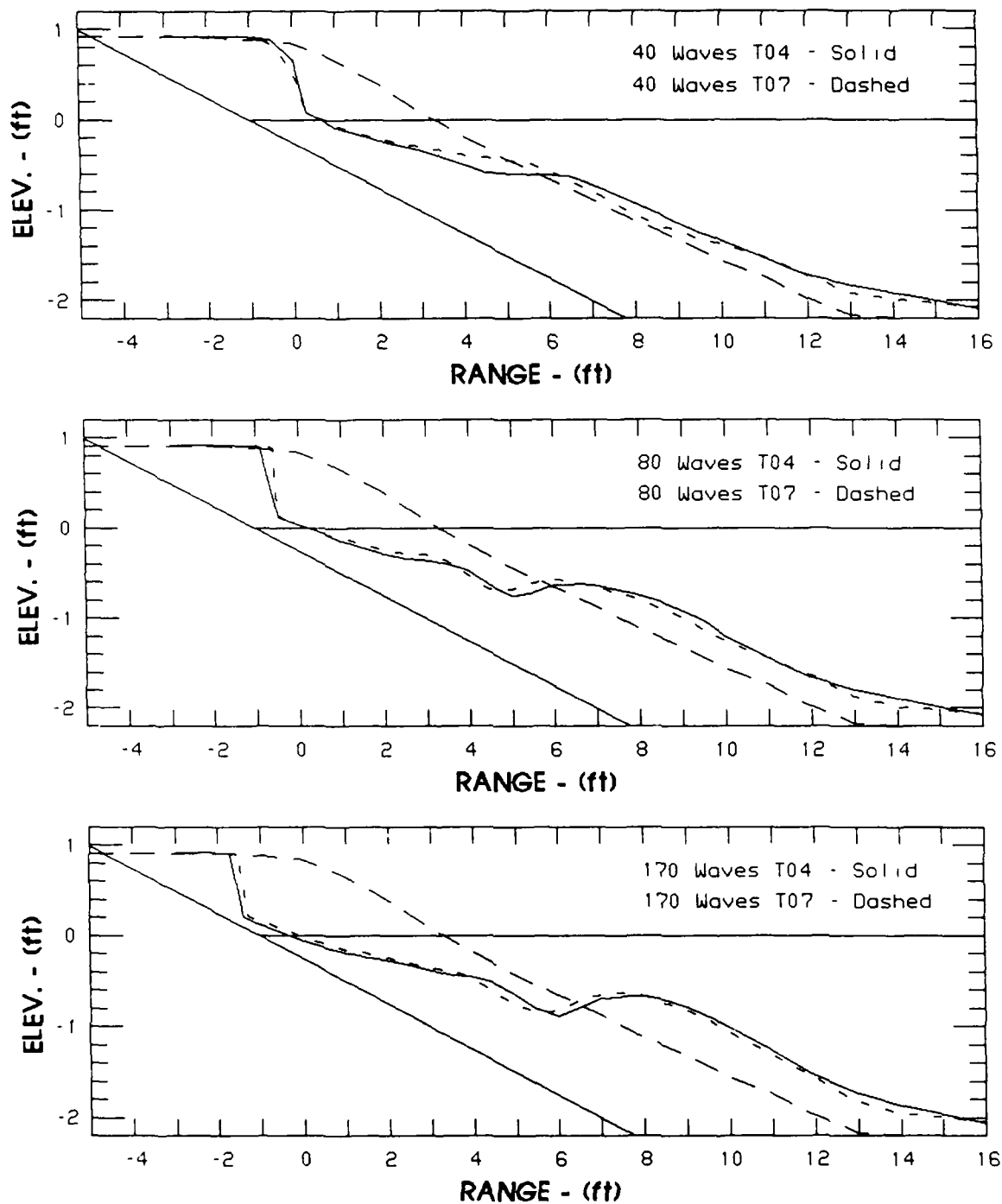


Figure E11. Equal H/wT parameters, T04 versus T07 (Sheet 1 of 3)

## EQUAL H/wT PARAMETERS

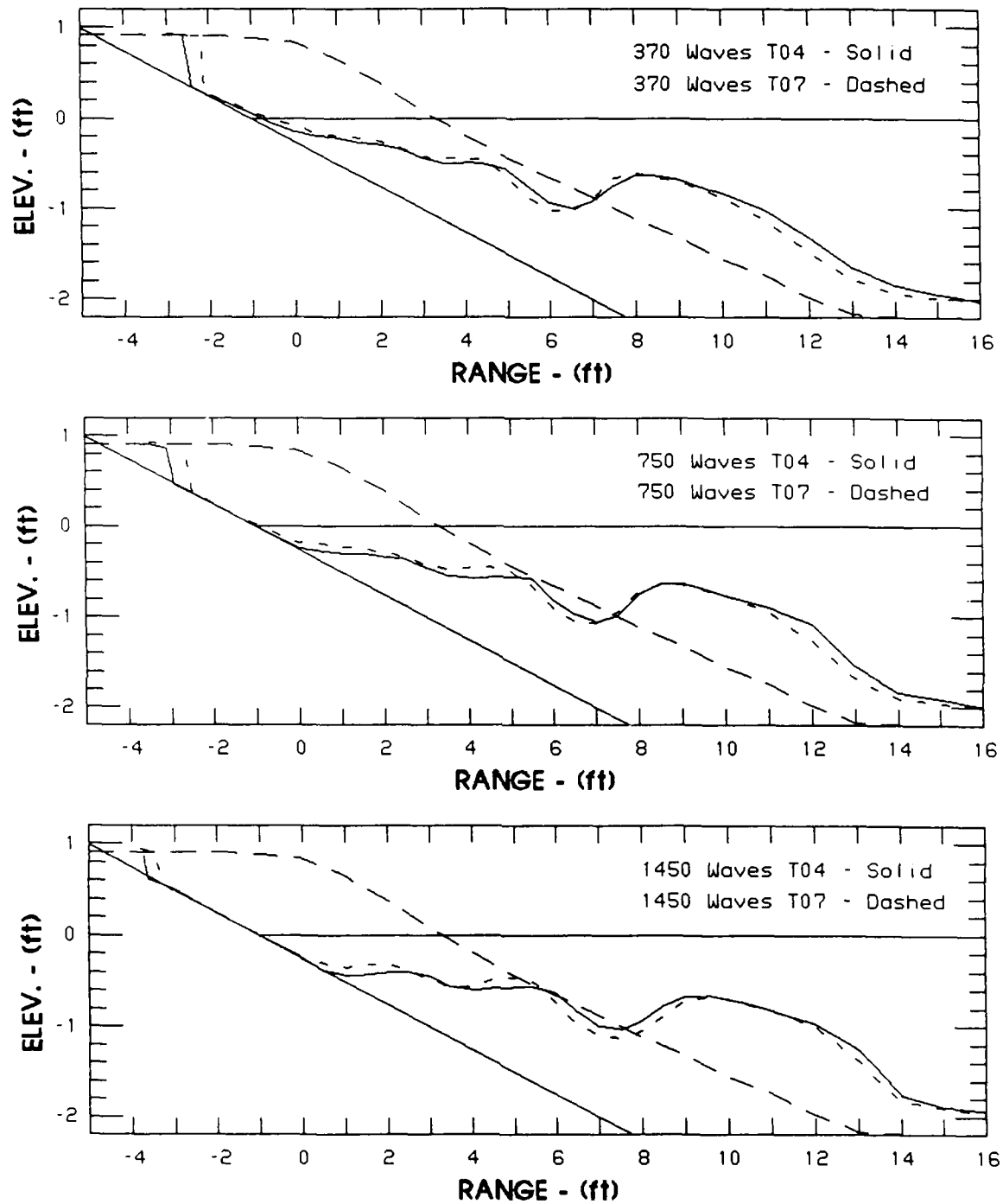


Figure E11. (Sheet 2 of 3)

## EQUAL H/wT PARAMETERS

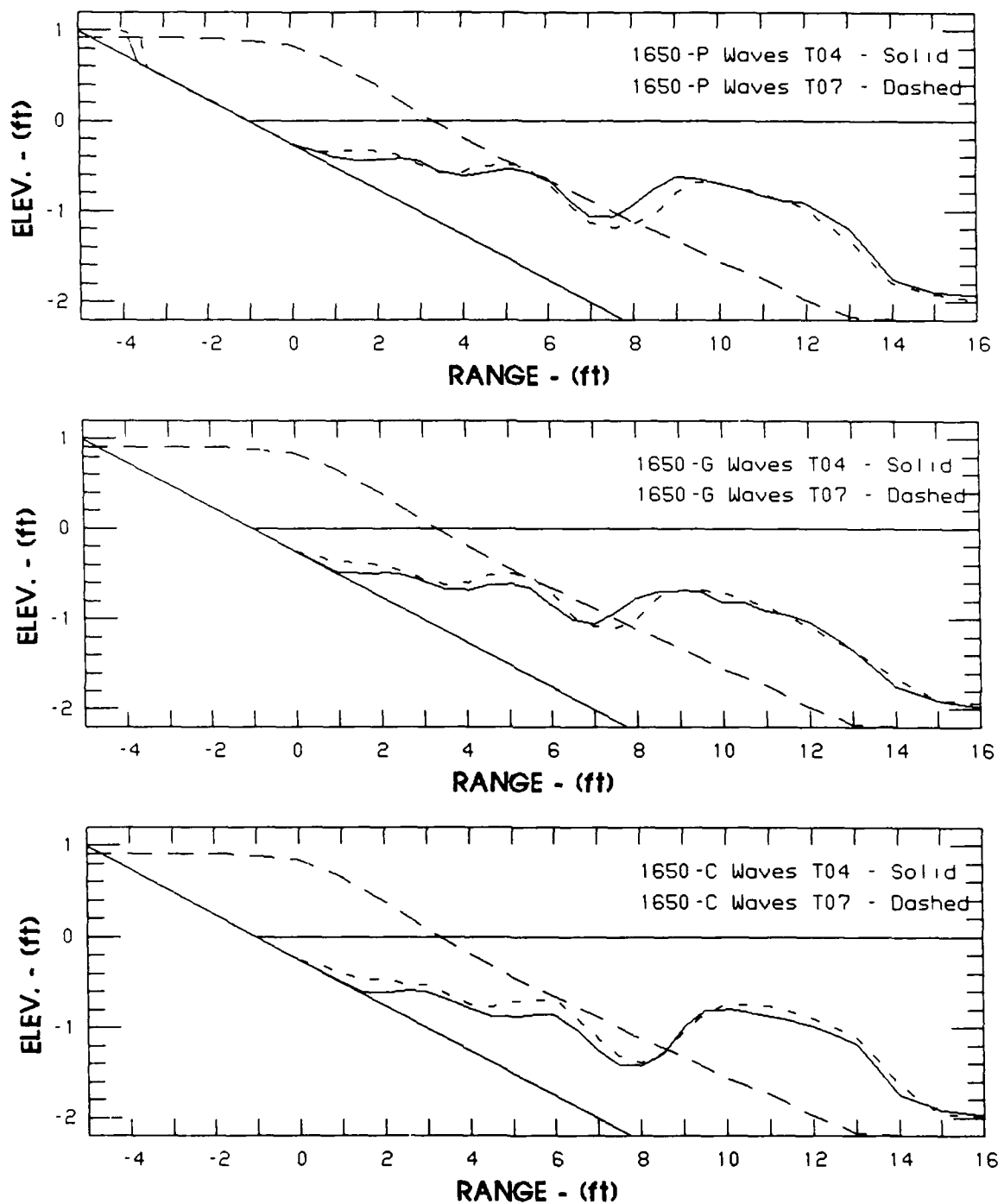


Figure E11. (Sheet 3 of 3)

# INITIAL PROFILE - 40 WAVES

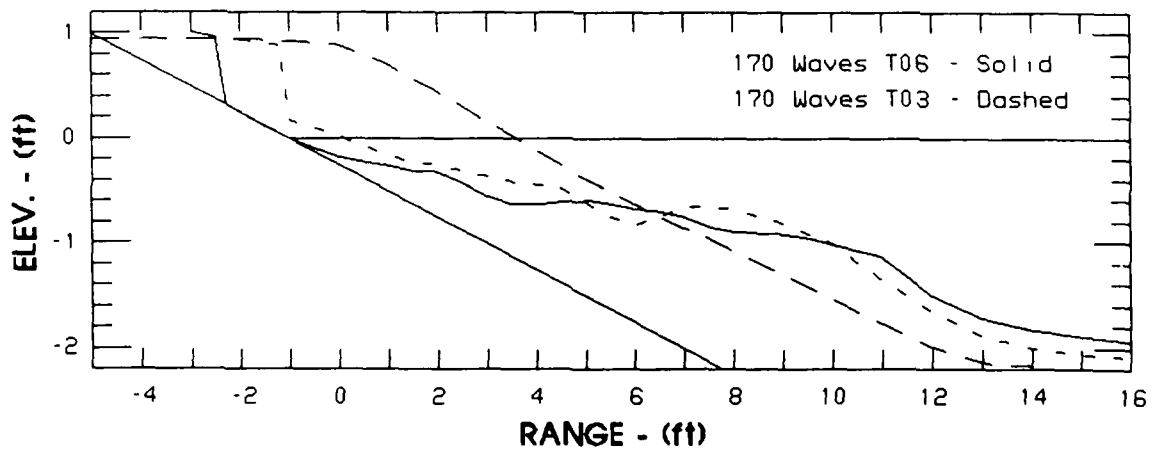
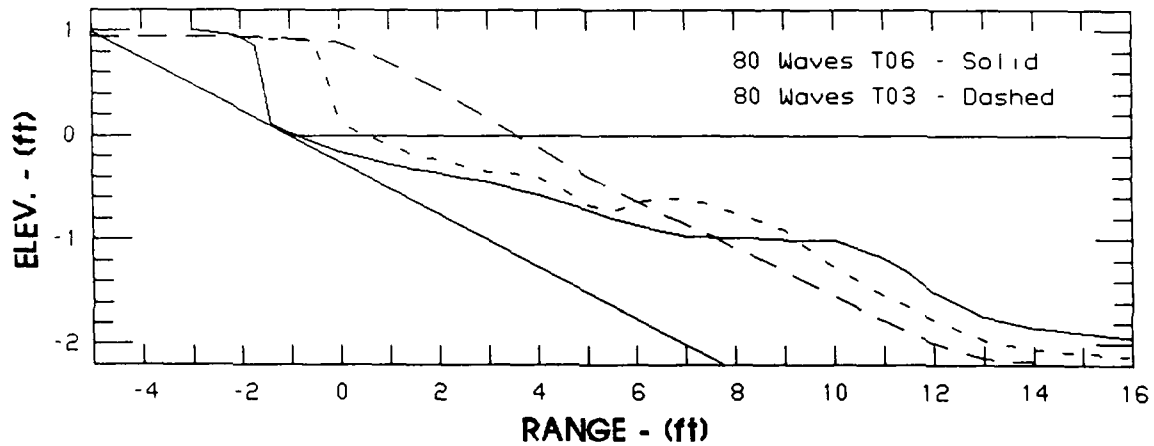
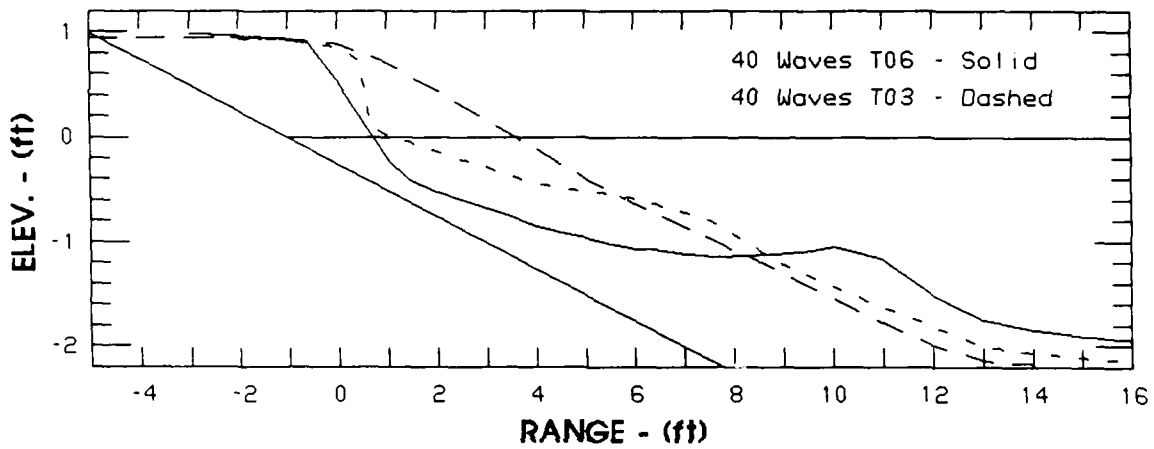


Figure E12. Initial profile at 40 waves, T06 versus T03  
(Sheet 1 of 4)

## INITIAL PROFILE - 40 WAVES

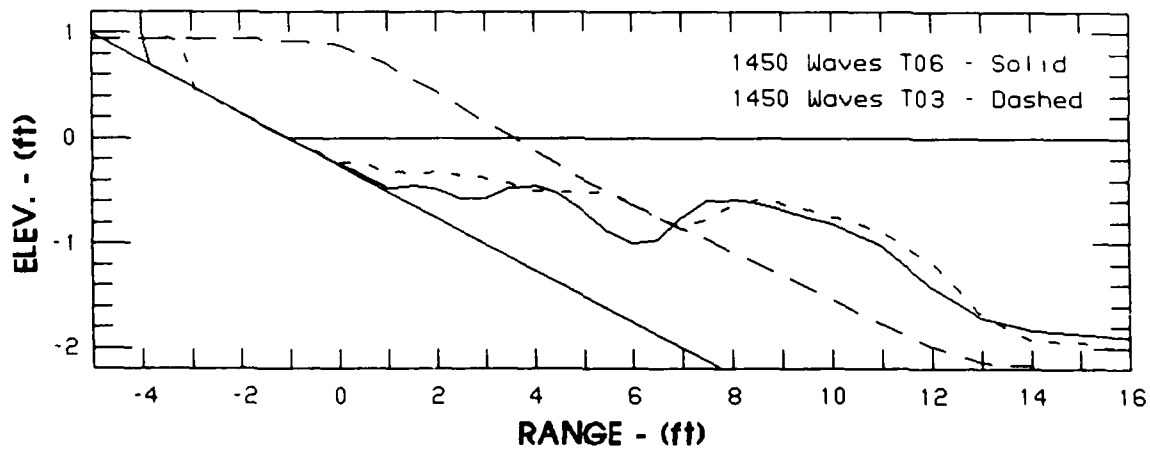
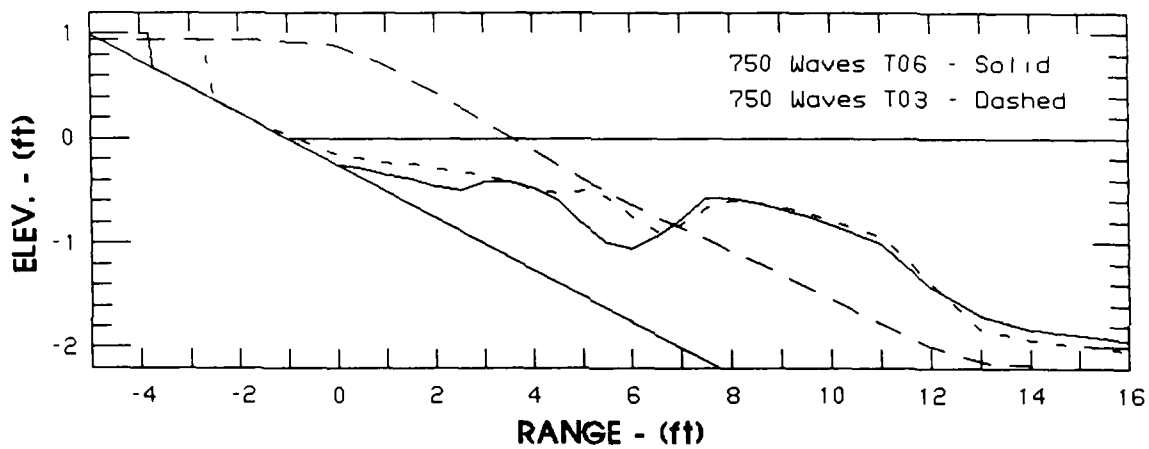
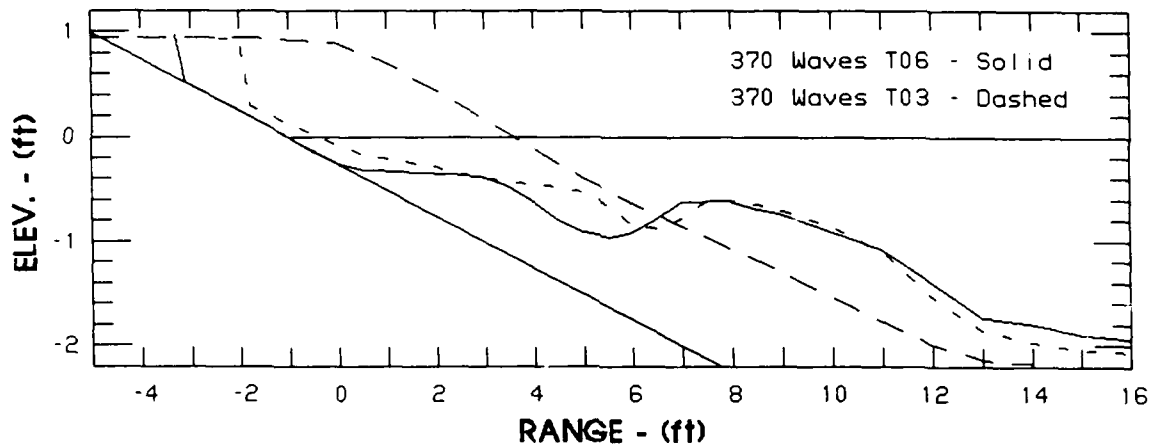


Figure E12. (Sheet 2 of 4)

## INITIAL PROFILE - 40 WAVES

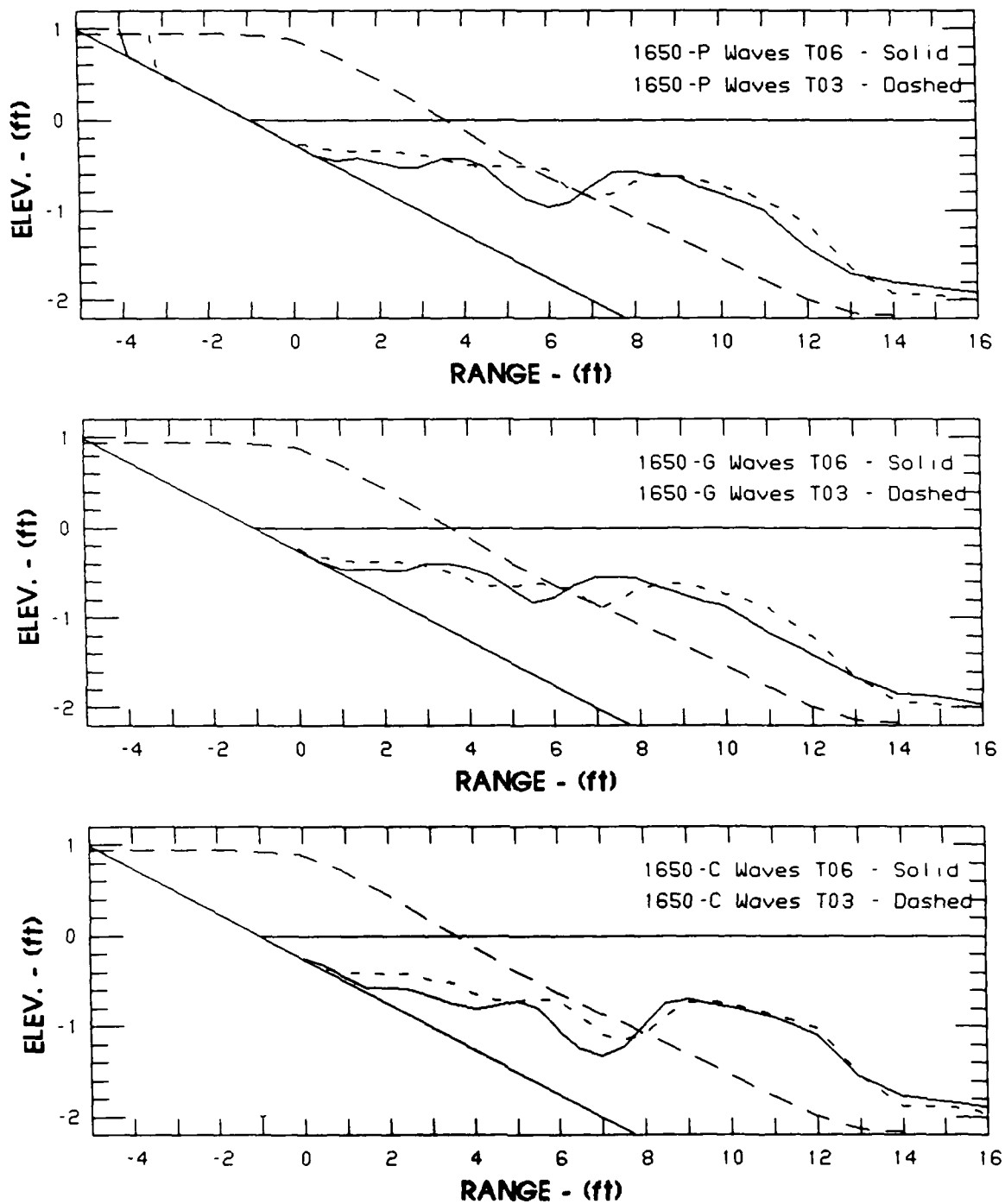


Figure E12. (Sheet 3 of 4)

## INITIAL PROFILE - 40 WAVES

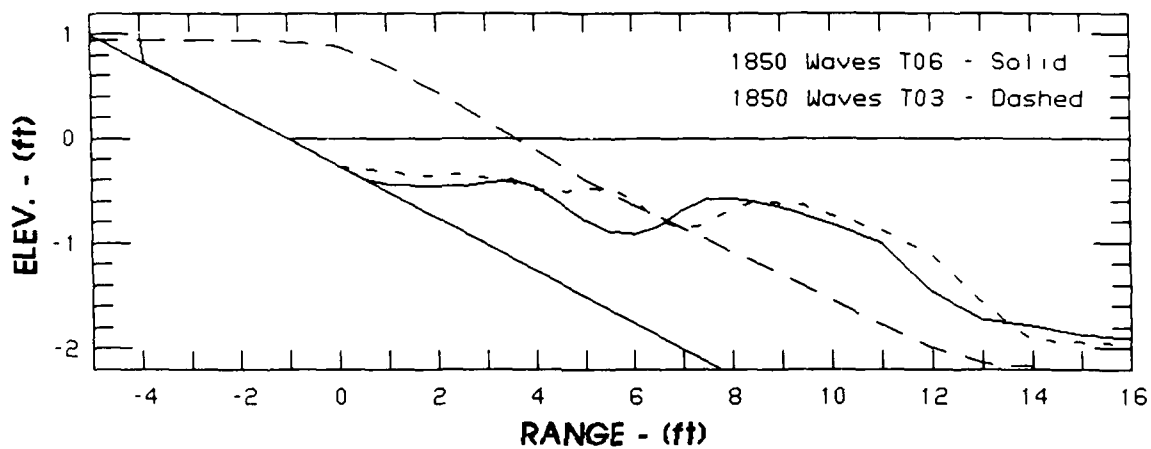


Figure E12. (Sheet 4 of 4)



## REDUCED SEDIMENT IMPACT

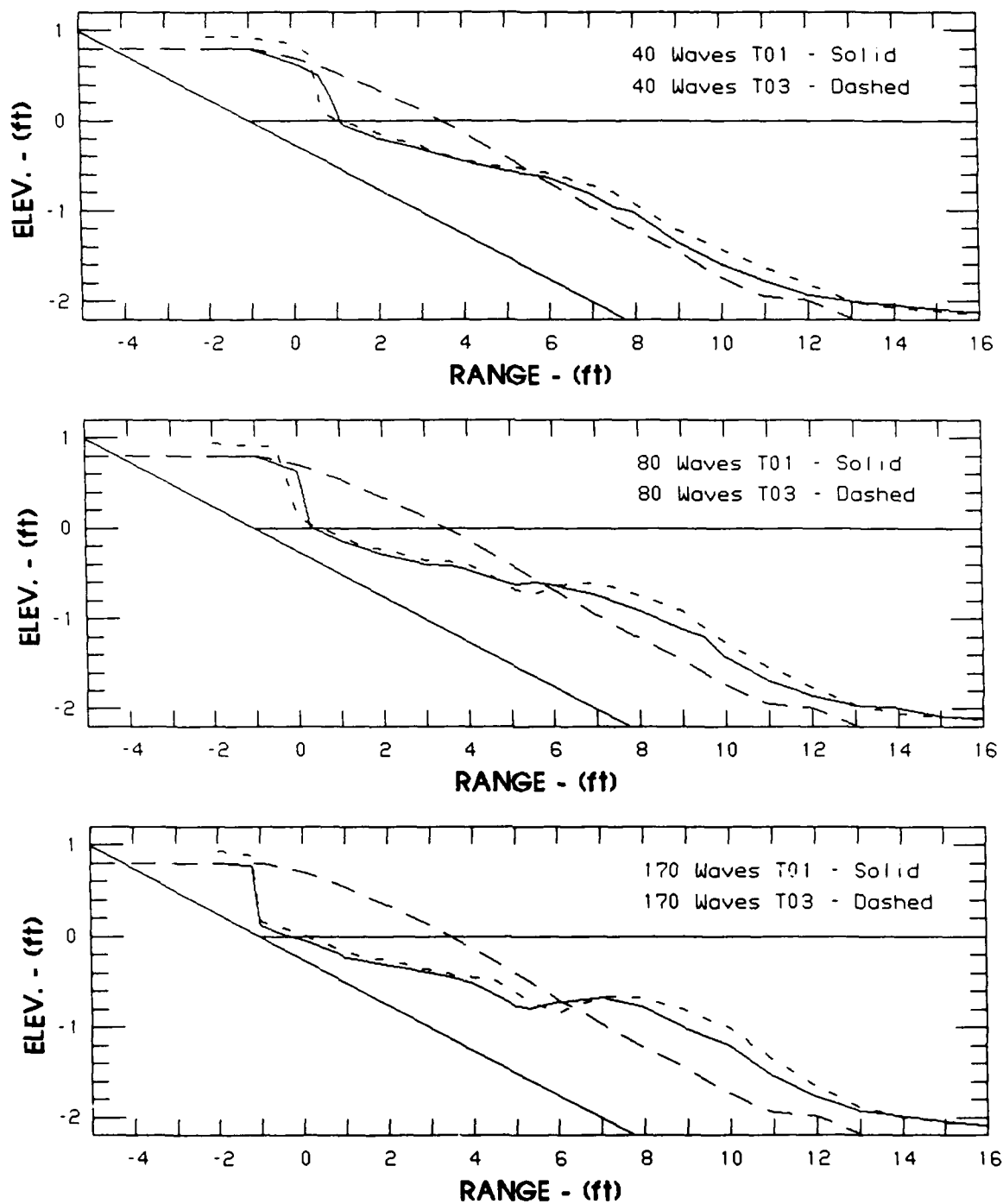


Figure E13. Reduced sediment comparison, T01 versus T03  
(Sheet 1 of 4)

## REDUCED SEDIMENT IMPACT

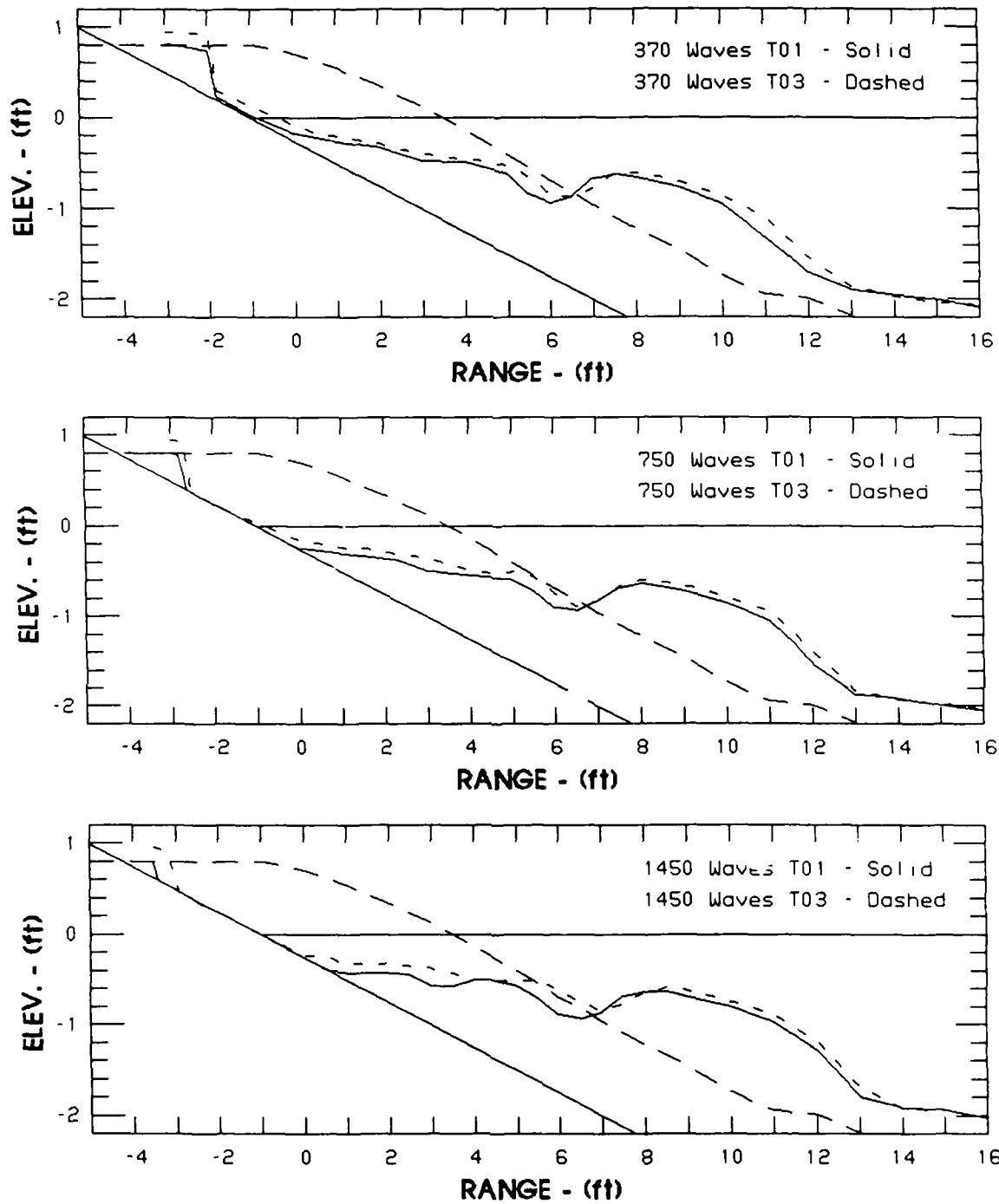


Figure E13. (Sheet 2 of 4)

## REDUCED SEDIMENT IMPACT

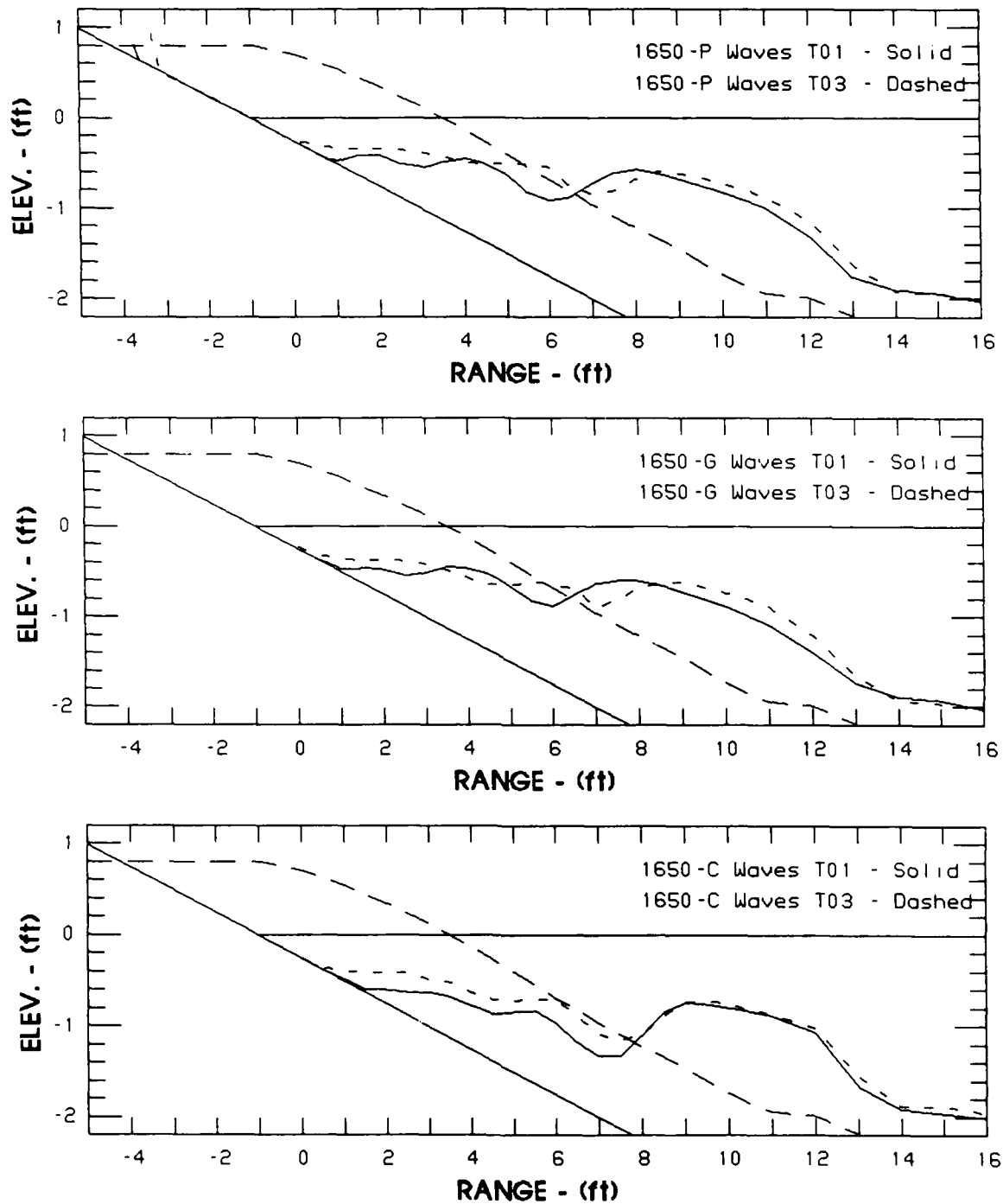


Figure E13. (Sheet 3 of 4)

## REDUCED SEDIMENT IMPACT

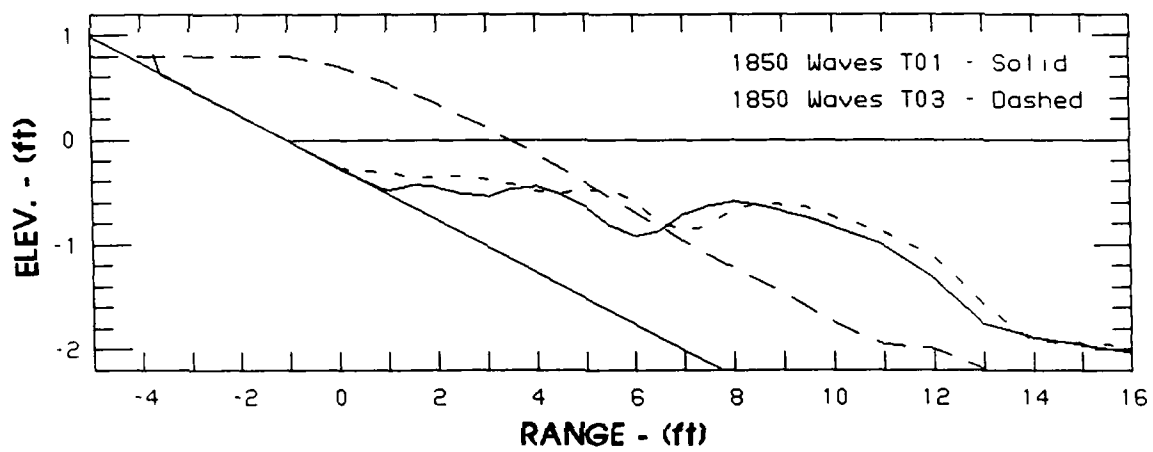


Figure E13. (Sheet 4 of 4)

# ABSORBING WAVE BOARD

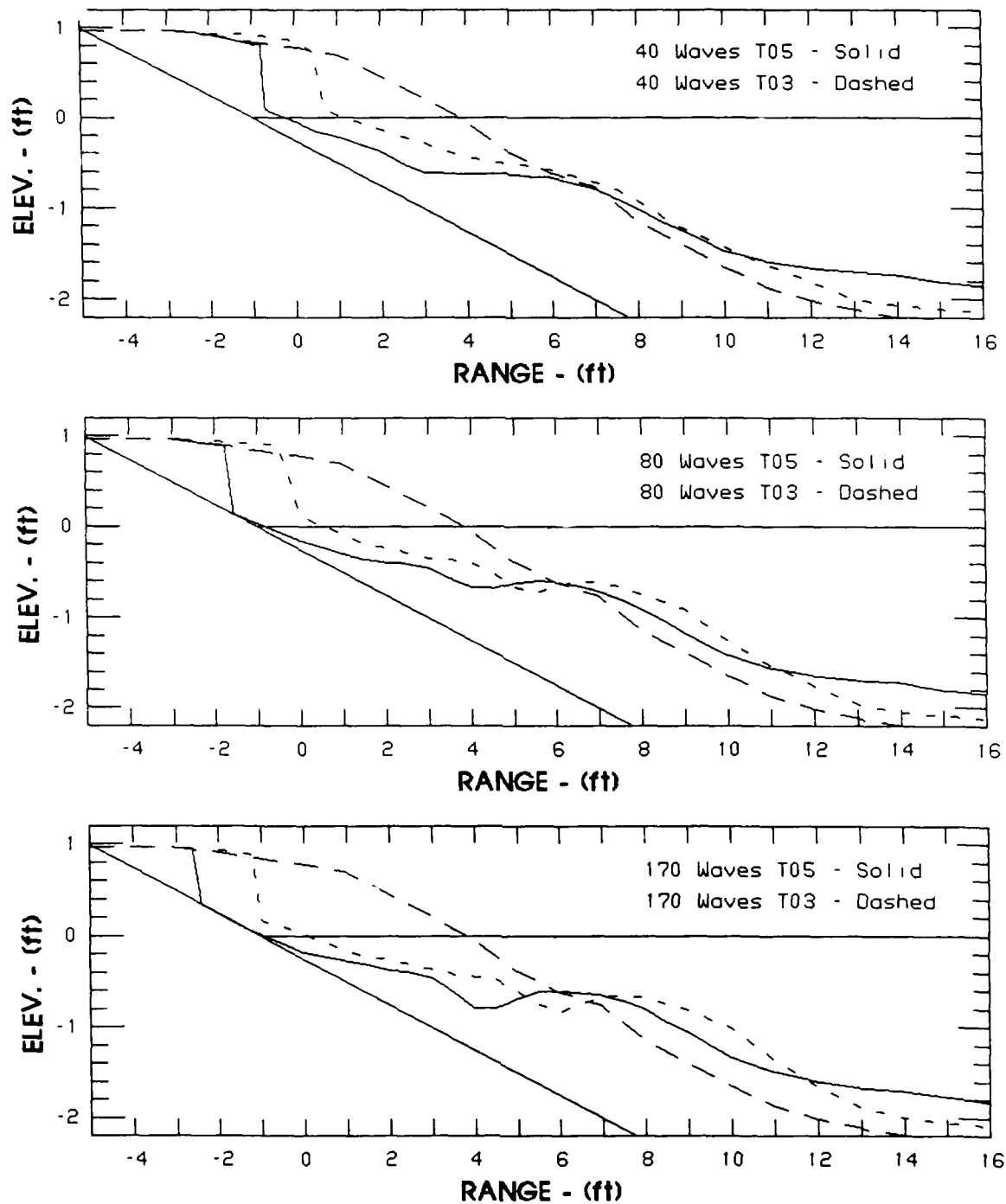


Figure E14. Absorbing wave board test, T05 versus T03  
(Sheet 1 of 3)

## ABSORBING WAVE BOARD

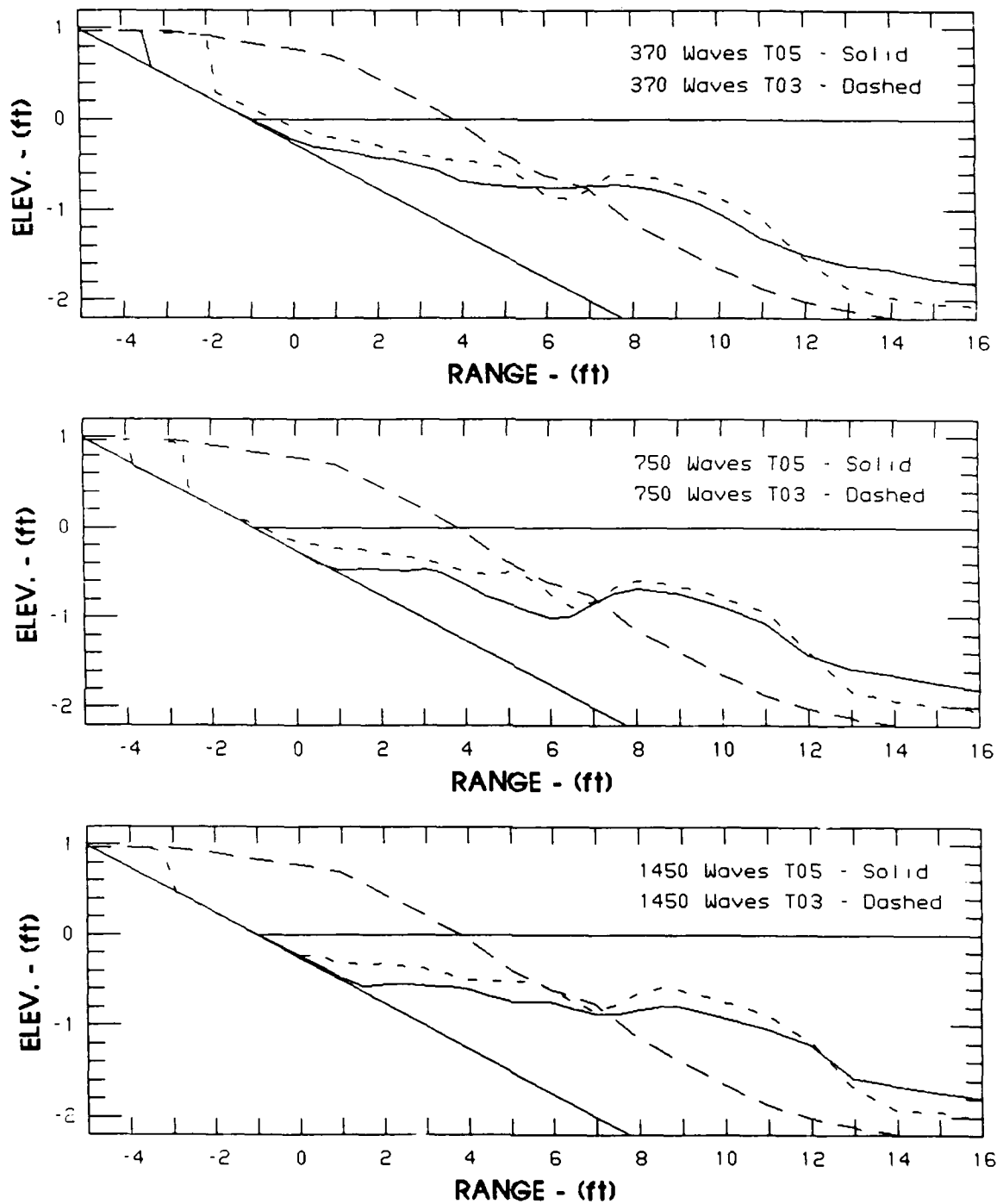


Figure E14. (Sheet 2 of 3)

## ABSORBING WAVE BOARD

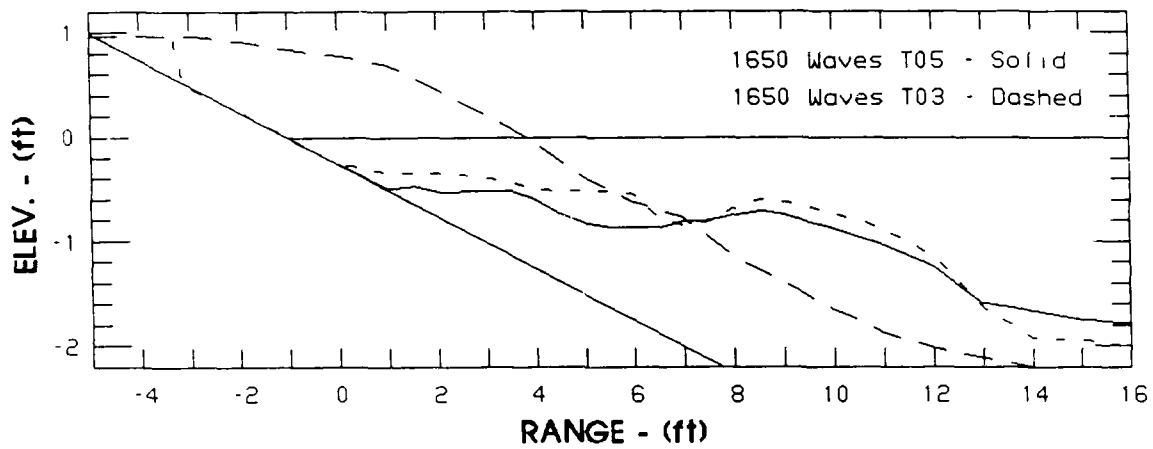


Figure E14. (Sheet 3 of 3)

# IRREGULAR H<sub>1/3</sub> = H<sub>mono</sub>

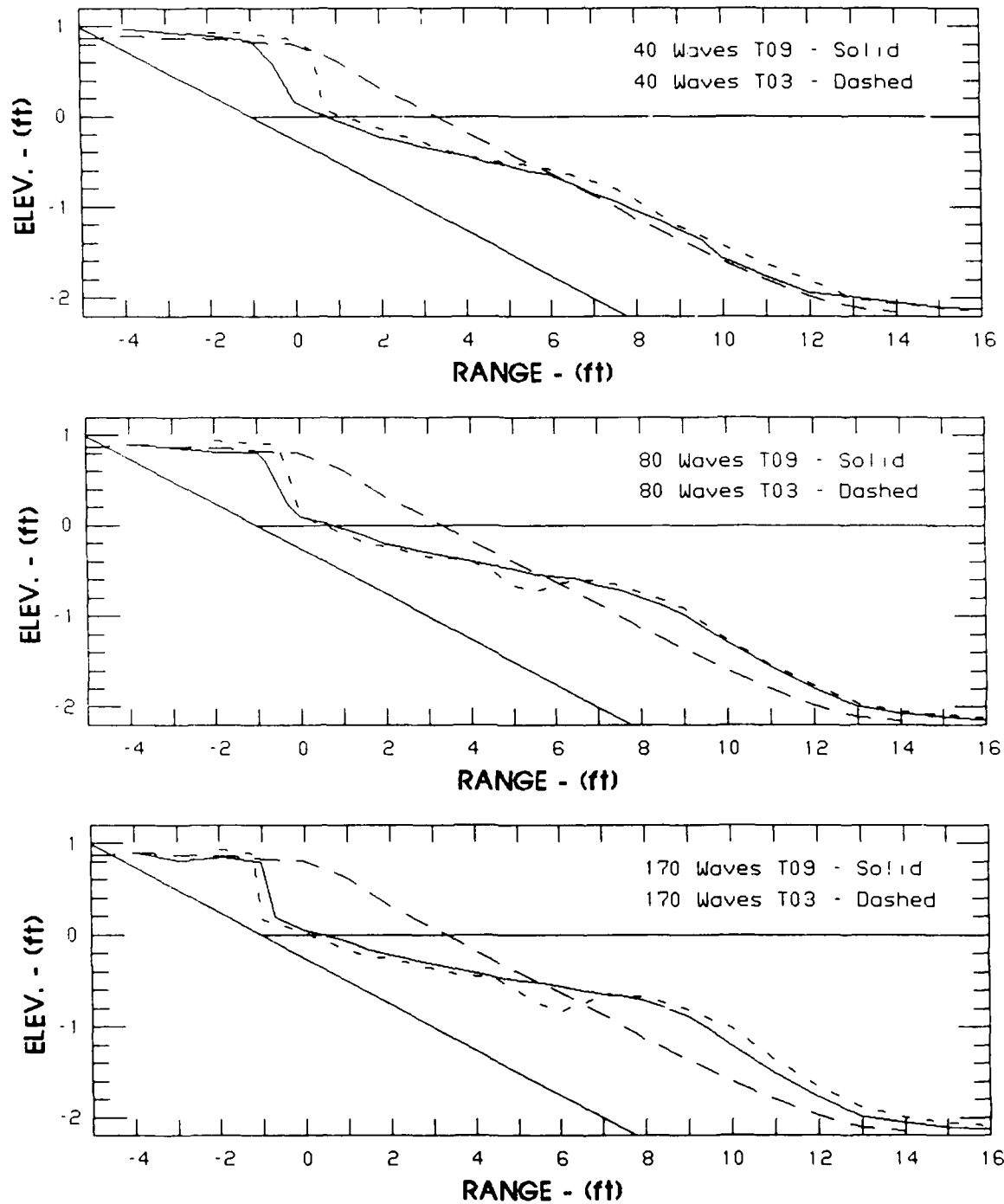


Figure E15. Irregular wave comparison,  $H_{1/3}$  equals  $H_{mono}$   
(Sheet 1 of 3)



## IRREGULAR H1/3 • Hmono

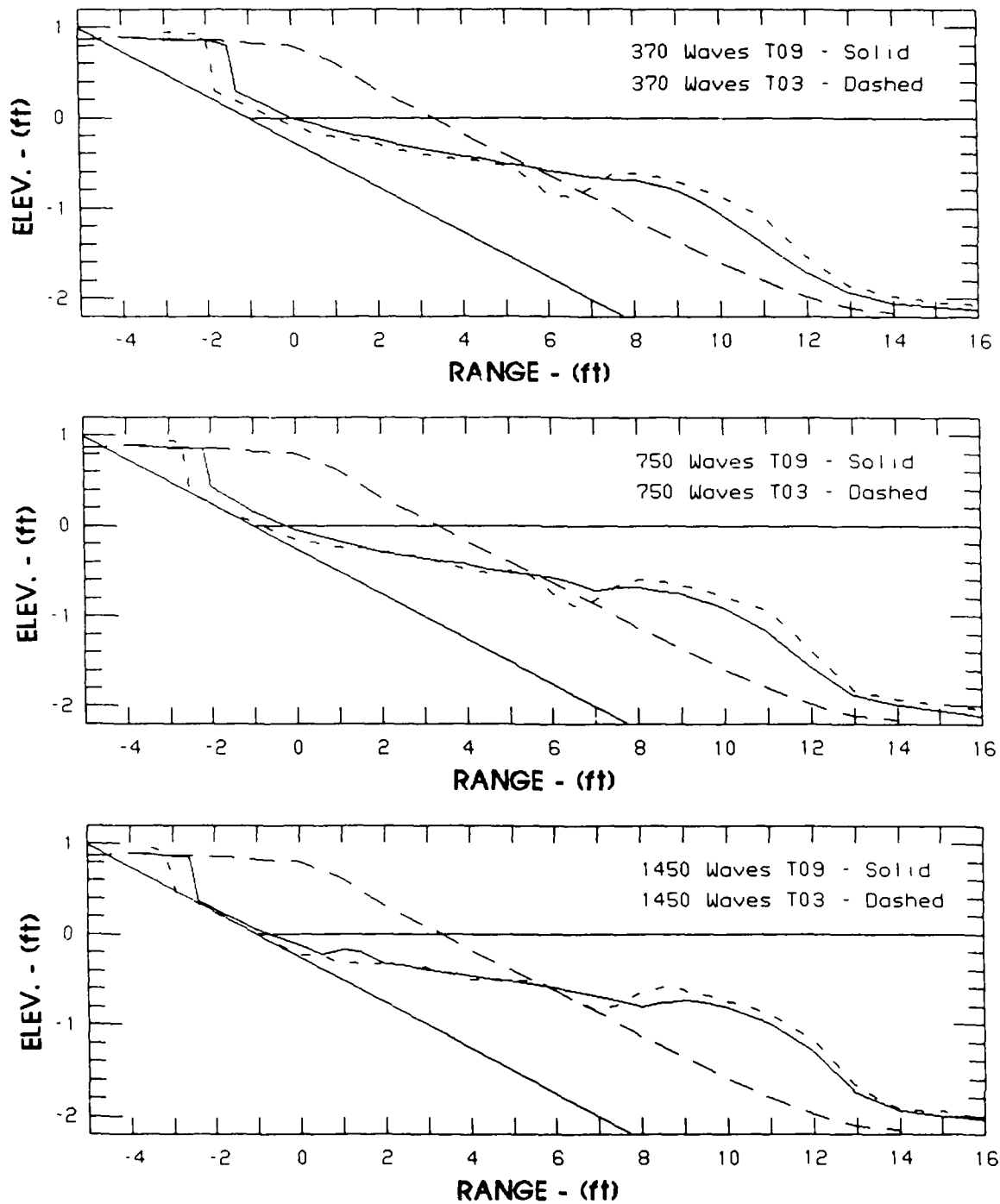


Figure E15. (Sheet 2 of 3)

## IRREGULAR H1/3 = Hmono

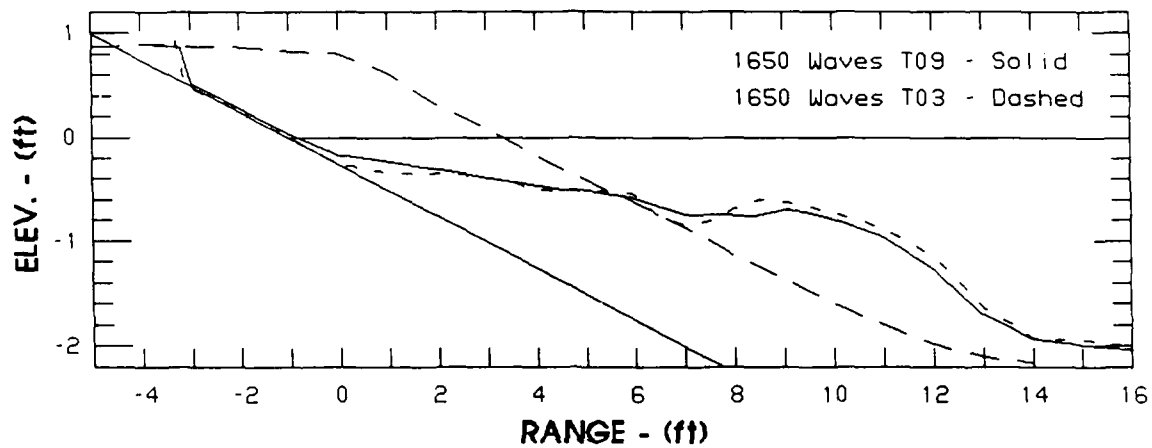


Figure E15. (Sheet 3 of 3)

# IRREGULAR H<sub>1/3</sub> = 141% H<sub>mono</sub>

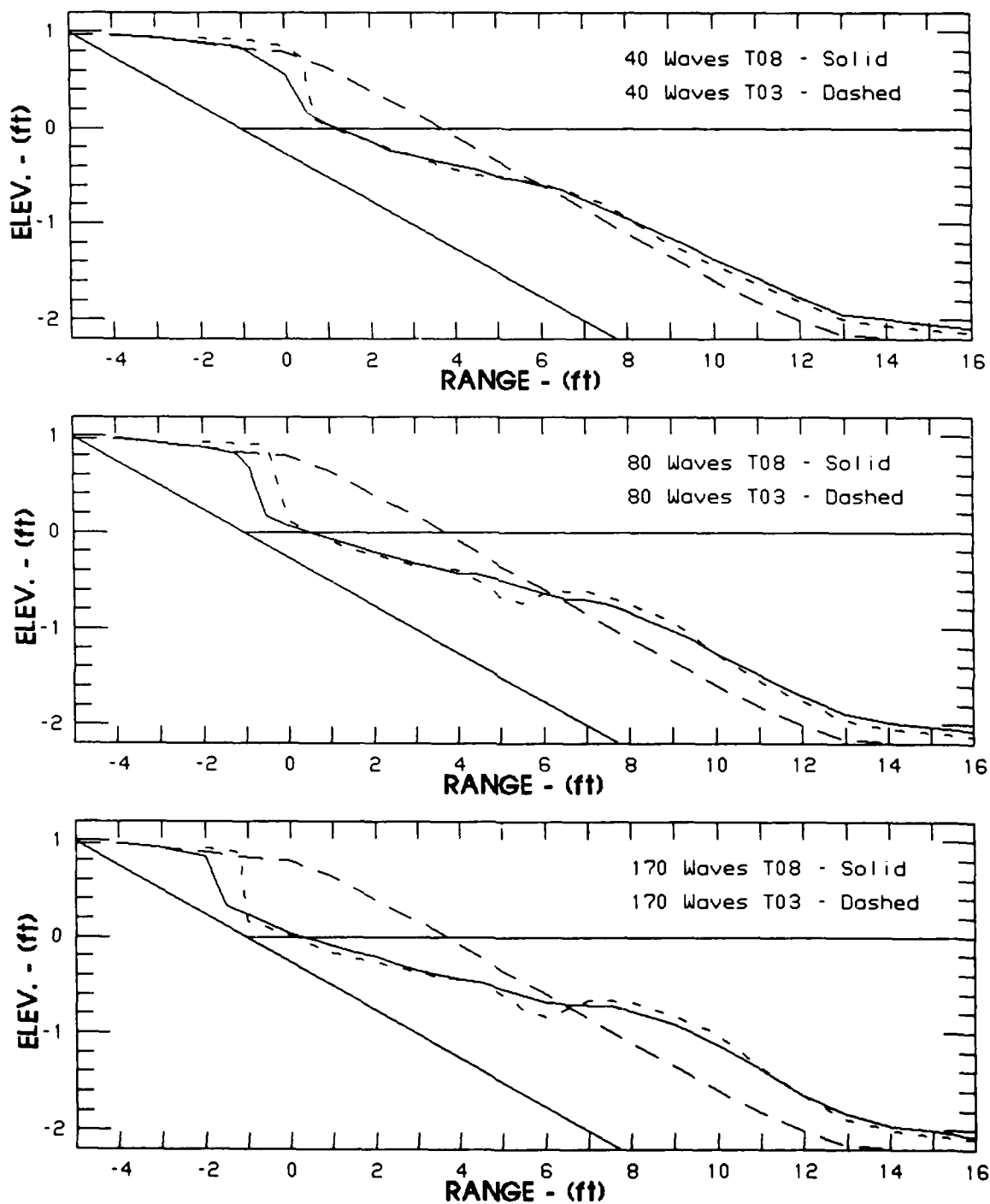


Figure E16. Irregular wave comparison, H<sub>1/3</sub> equals 141 percent H<sub>mono</sub> (Sheet 1 of 3)

# IRREGULAR H173 - 141% Hmono

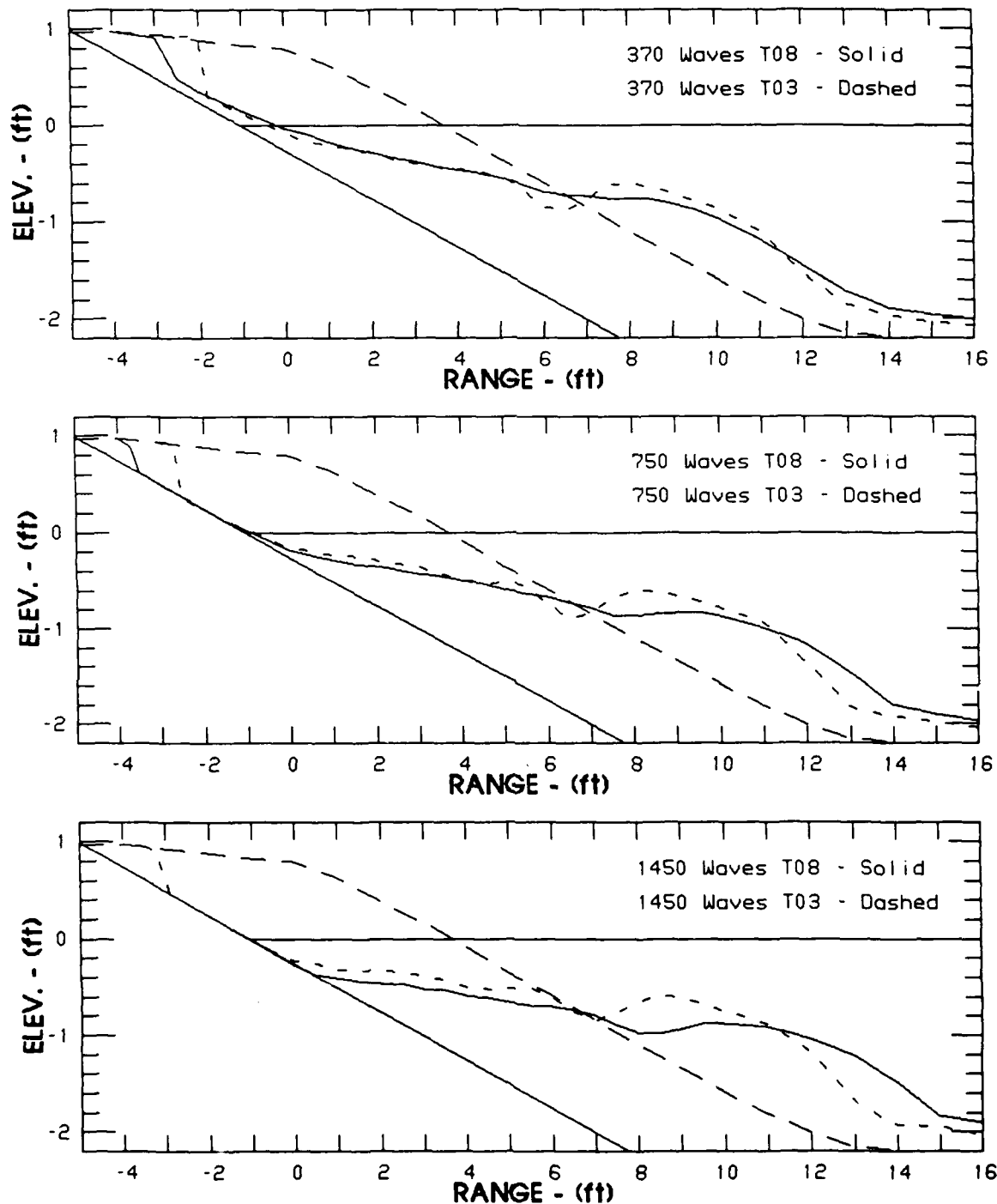


Figure E16. (Sheet 2 of 3)

## IRREGULAR H1/3 = 141% Hmono

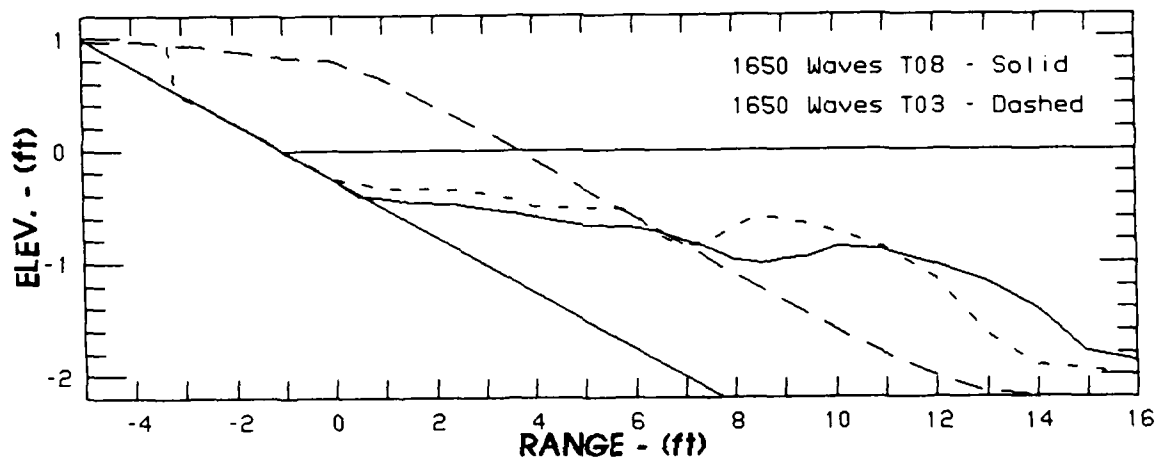


Figure E16. (Sheet 3 of 3)

## IRREGULAR WAVE PERTURBATION

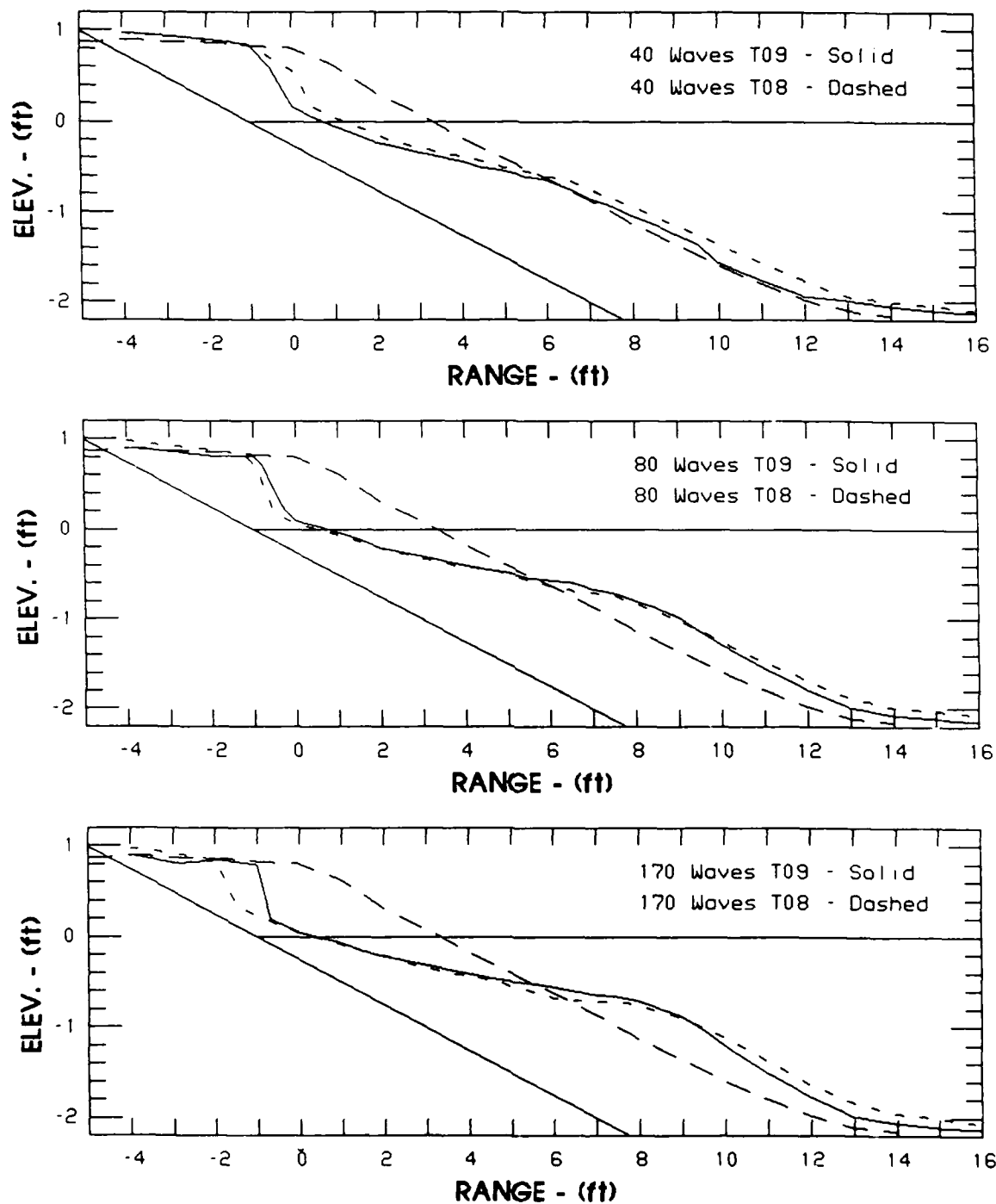


Figure E17. Irregular wave perturbation, T09 versus T08  
(Sheet 1 of 3)

# IRREGULAR WAVE PERTURBATION

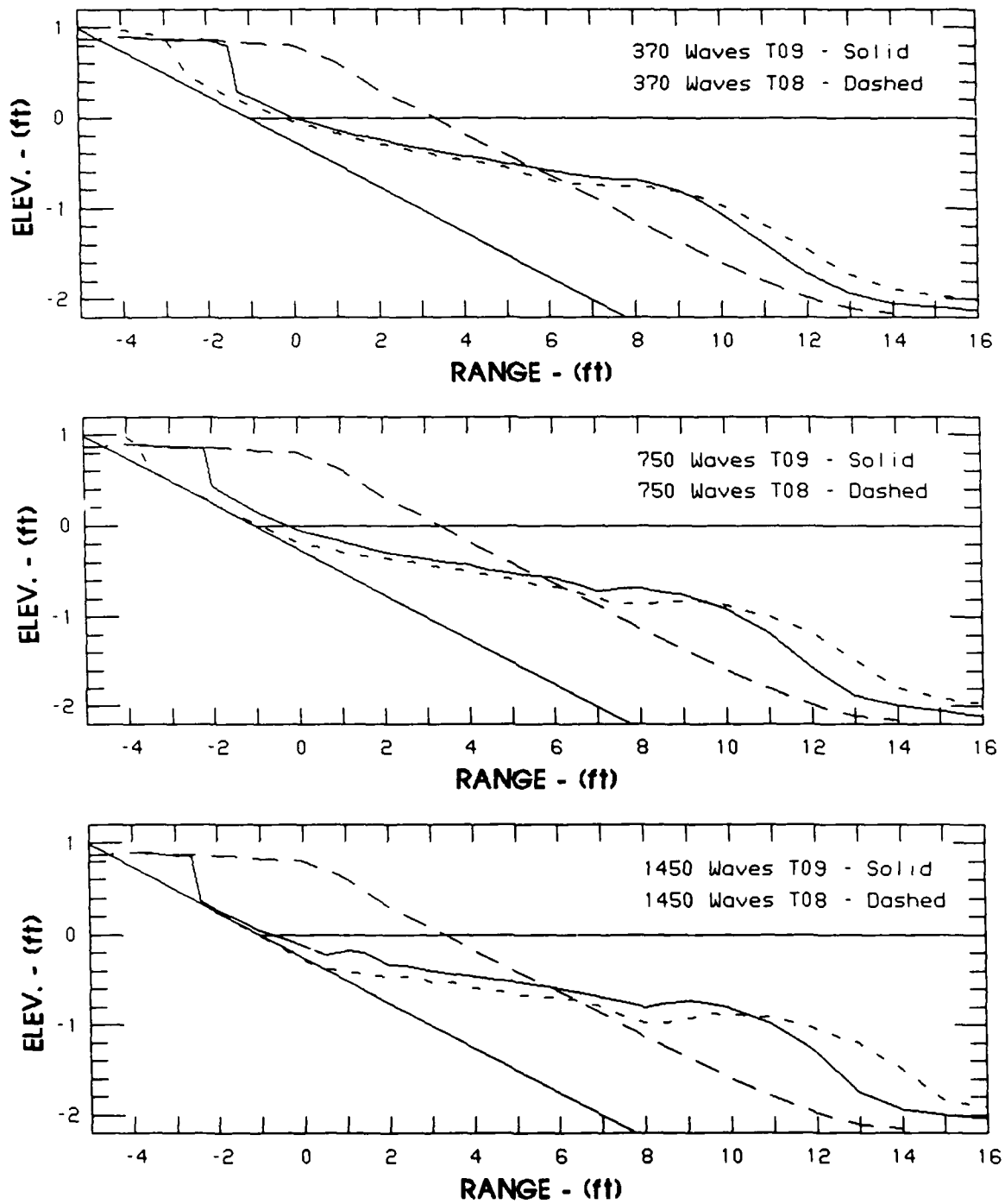


Figure E17. (Sheet 2 of 3)

## IRREGULAR WAVE PERTURBATION

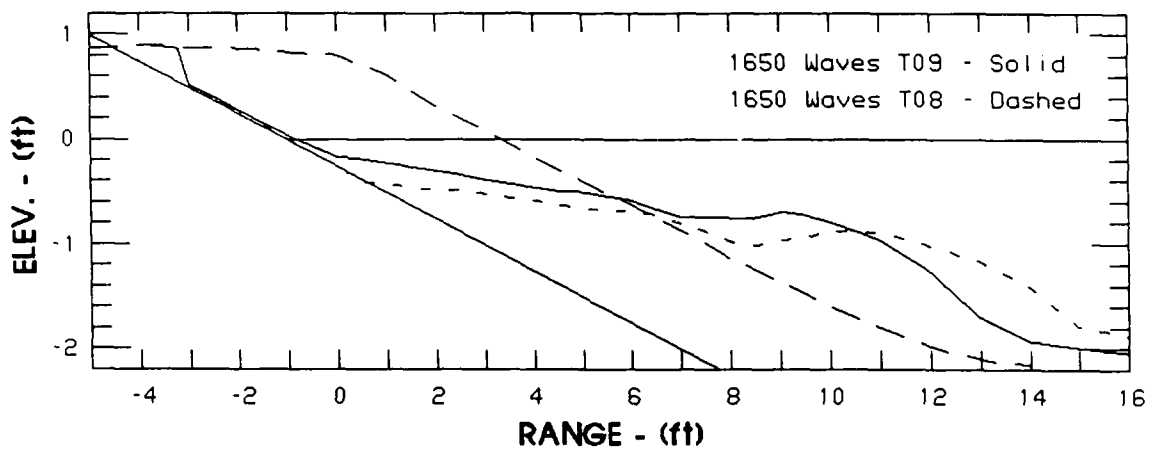


Figure E17. (Sheet 3 of 3)



## IRREGULAR T12 VERSUS T08

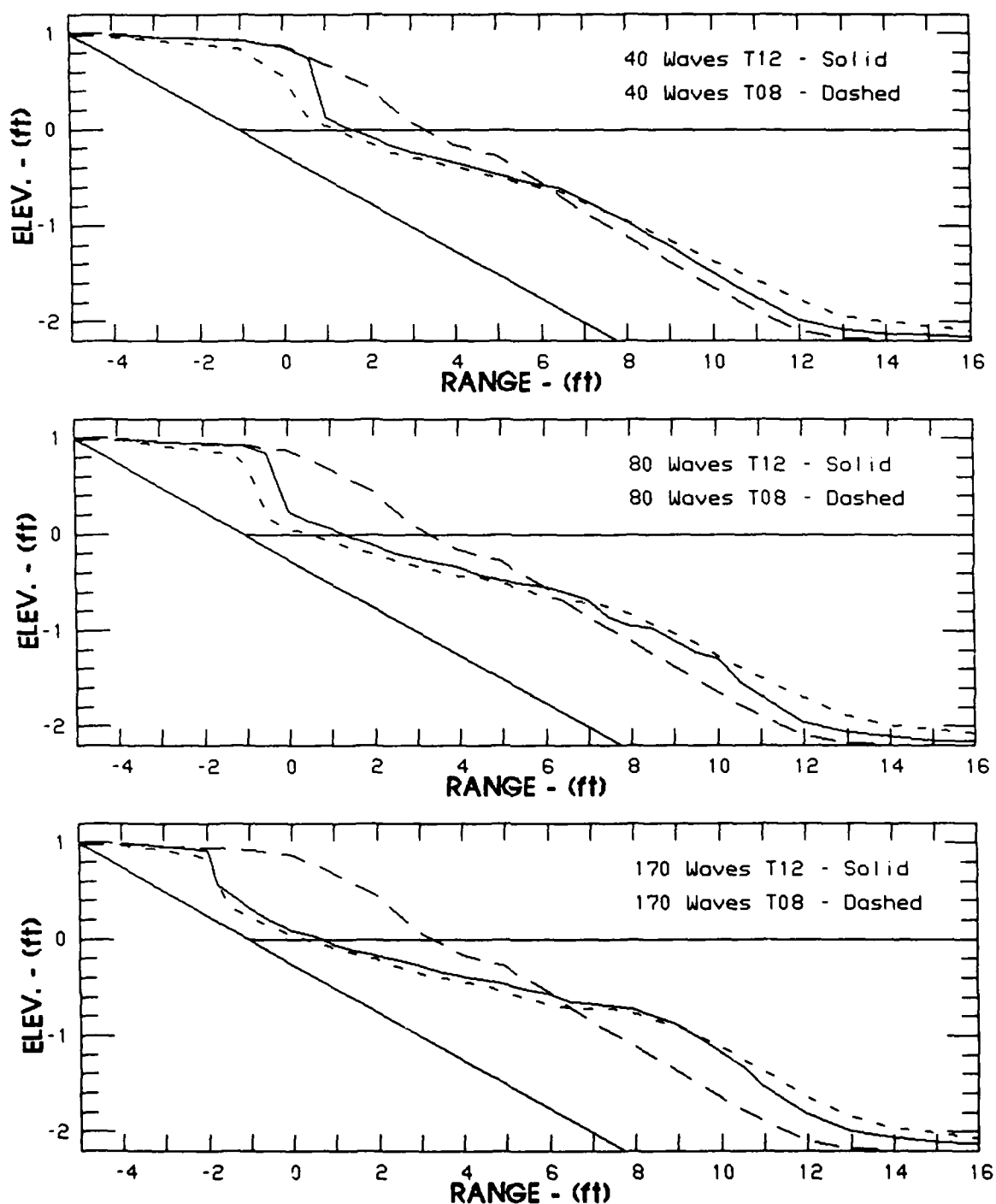


Figure E18. Irregular wave repeatability, T12 versus T08  
(Sheet 1 of 3)

## IRREGULAR T12 VERSUS T08

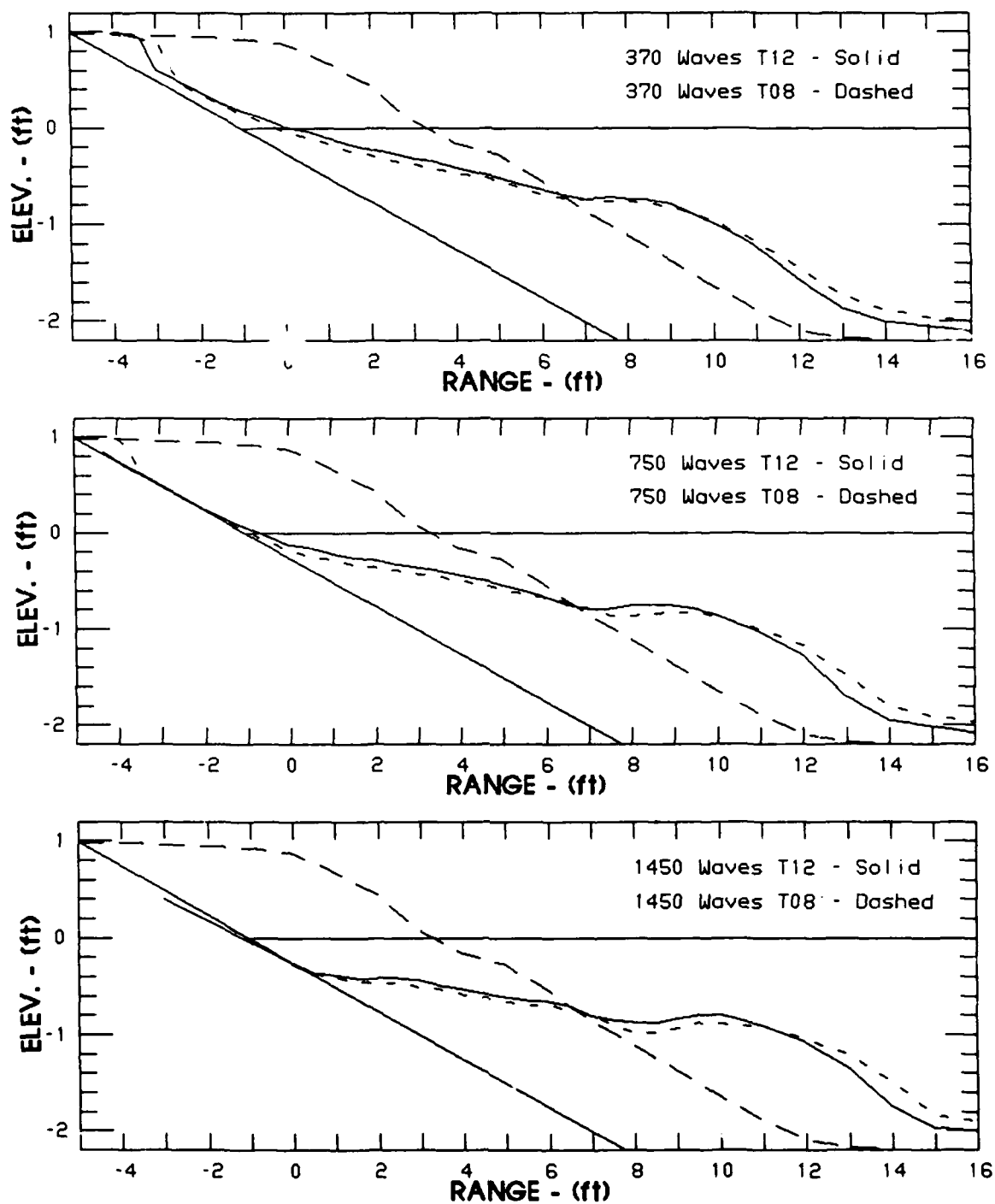


Figure E18. (Sheet 2 of 3)

## IRREGULAR T12 VERSUS T08

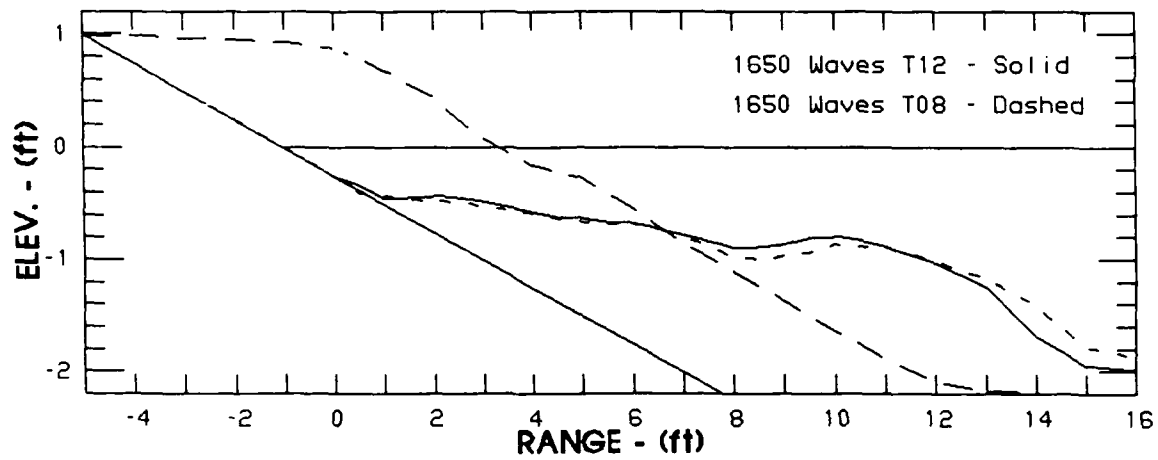


Figure E18. (Sheet 3 of 3)

## SEAWALL IMPACT - MONO. WAVES

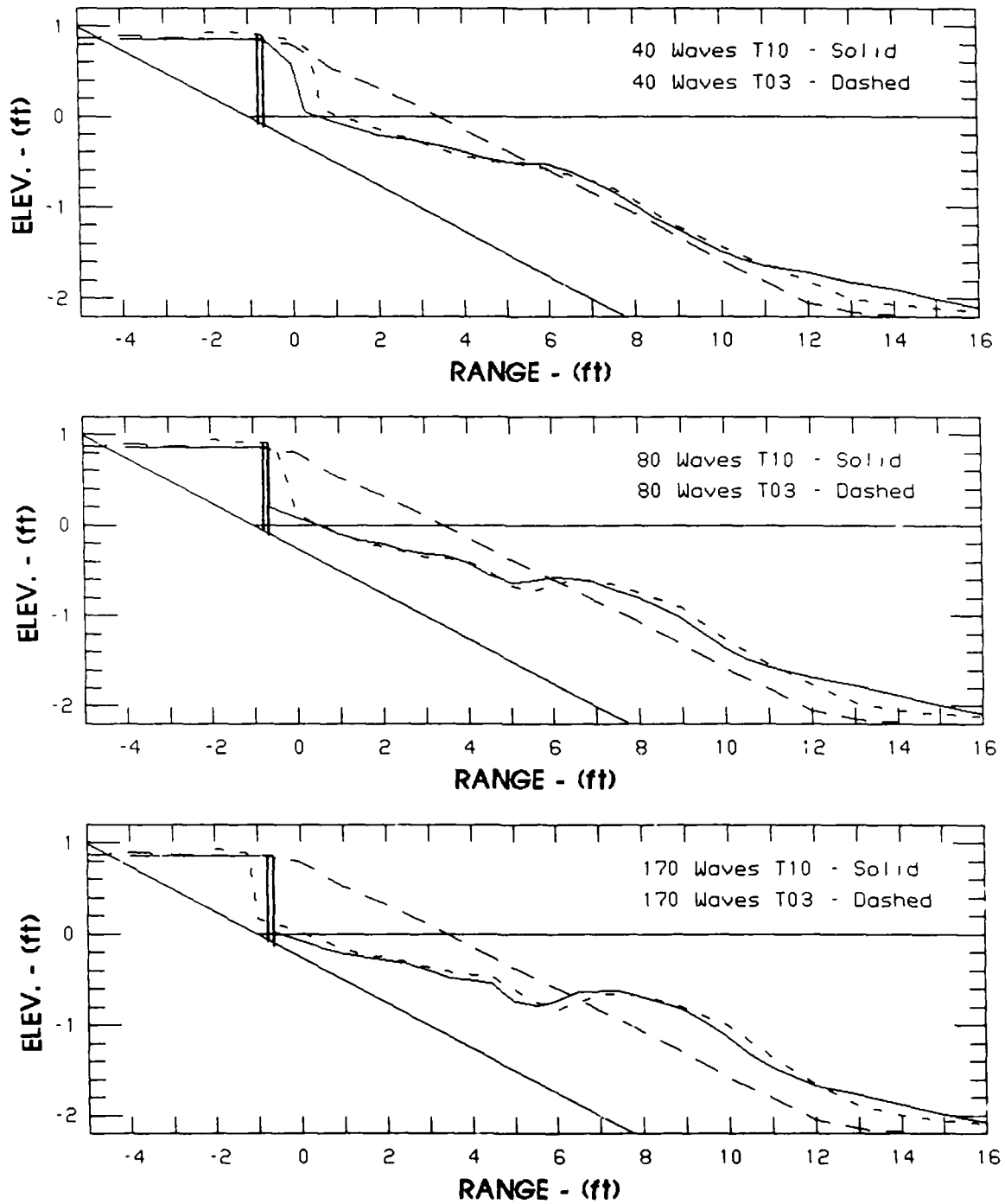


Figure E19. Seawall impacts under regular waves, T10 versus T03  
(Sheet 1 of 3)

## SEAWALL IMPACT - MONO. WAVES

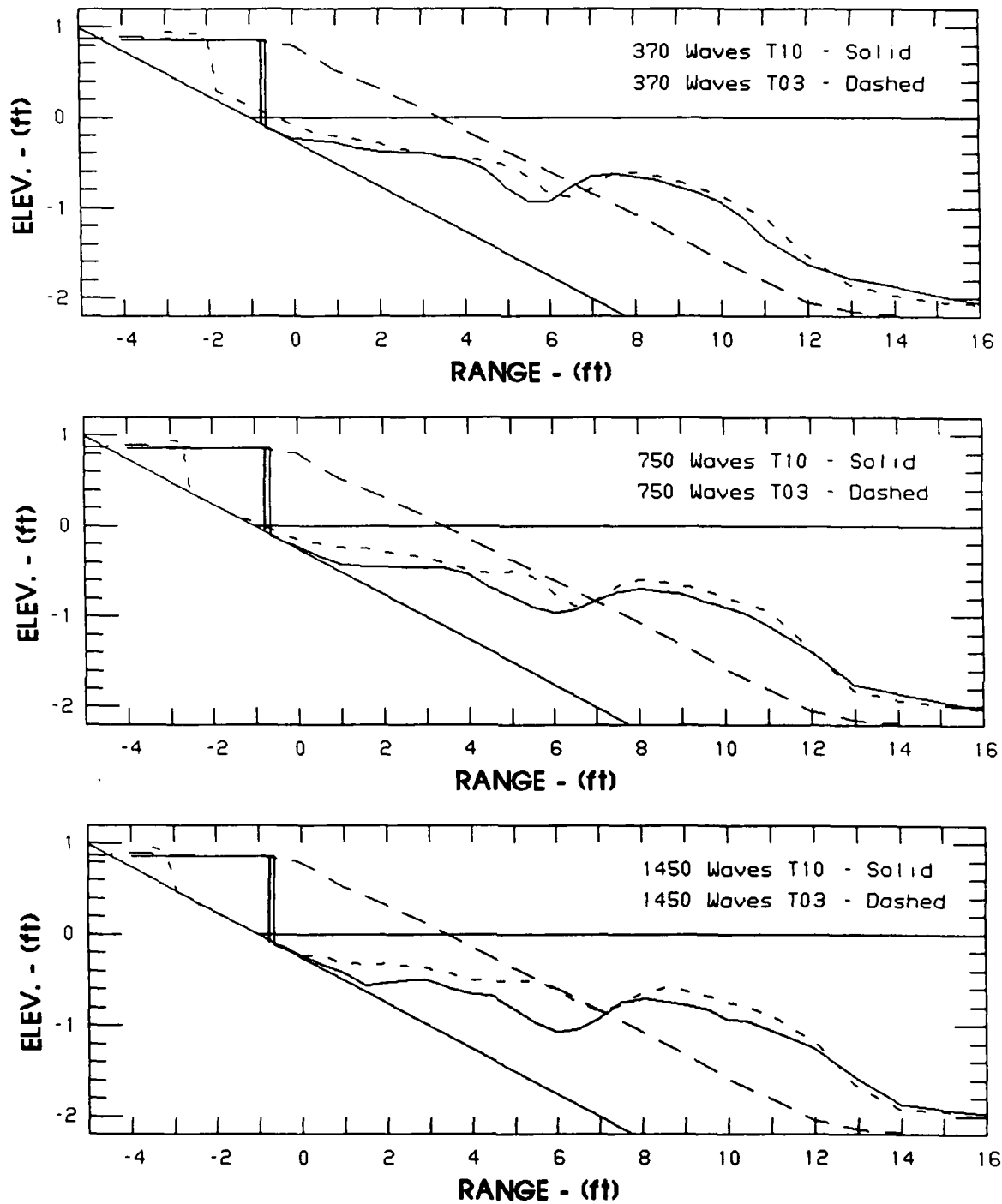


Figure E19. (Sheet 2 of 3)

## SEAWALL IMPACT - MONO. WAVES

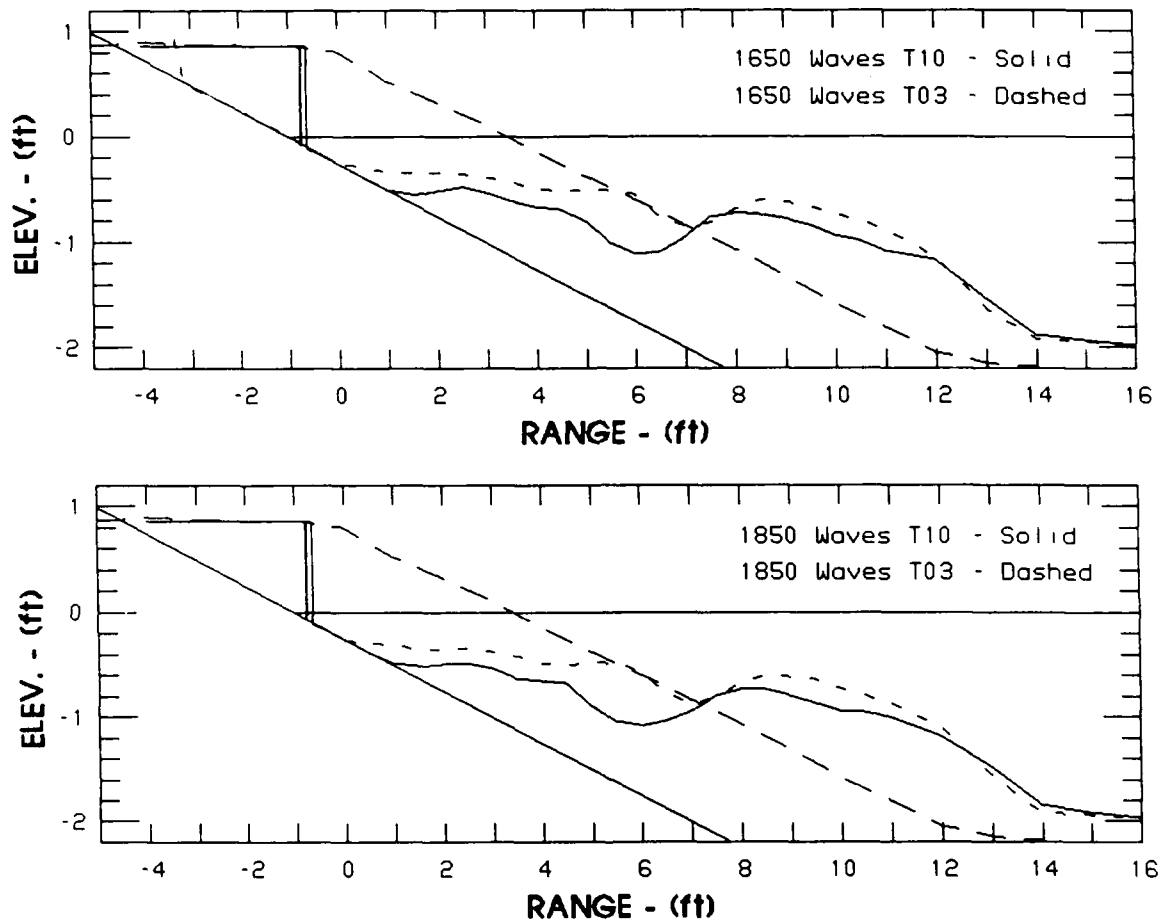


Figure E19. (Sheet 3 of 3)

# SEAWALL IMPACT - IRREGULAR WAVES

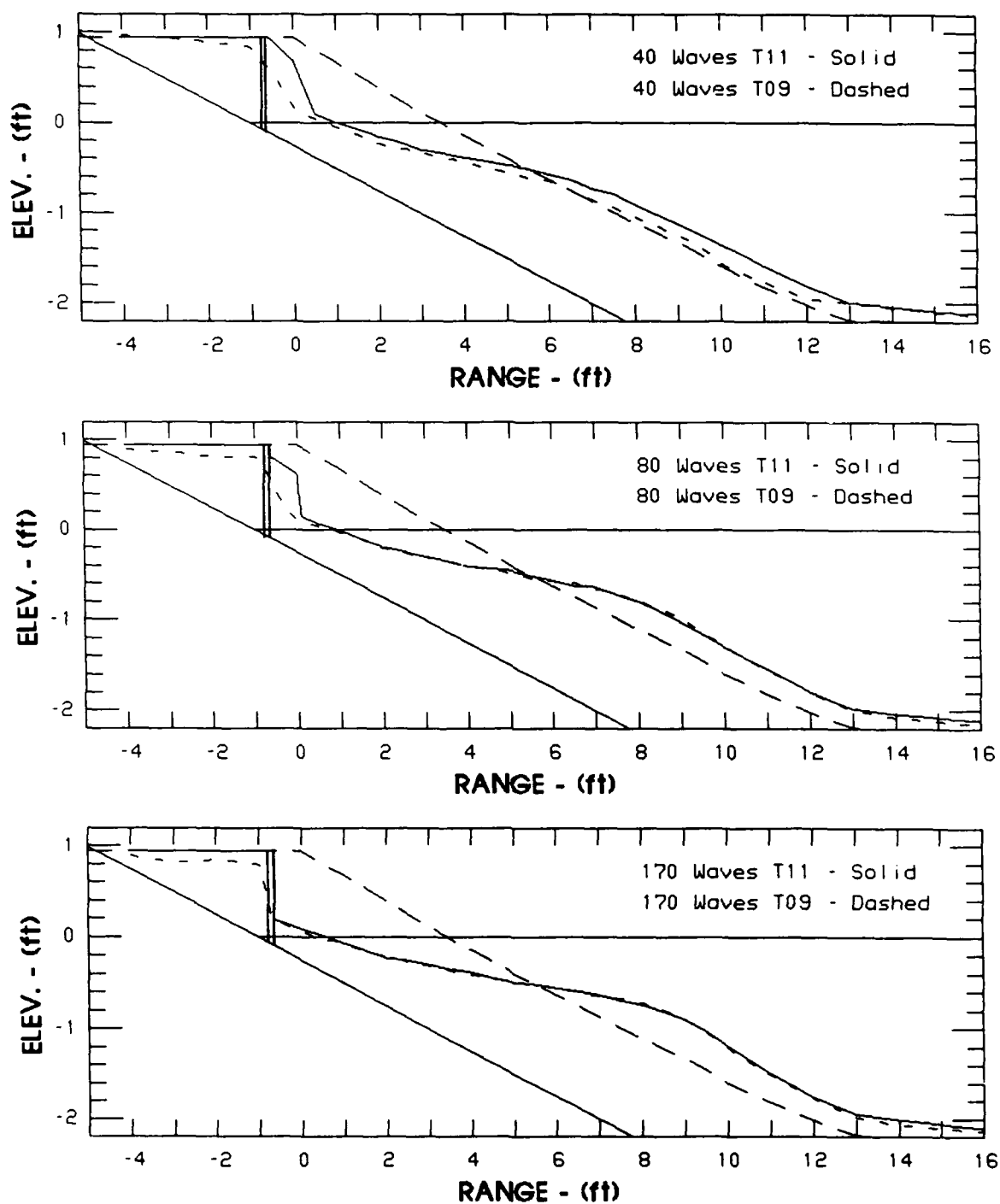


Figure E20. Seawall impacts under irregular waves, T11 versus T09 (Sheet 1 of 3)

## SEAWALL IMPACT - IRREGULAR WAVES

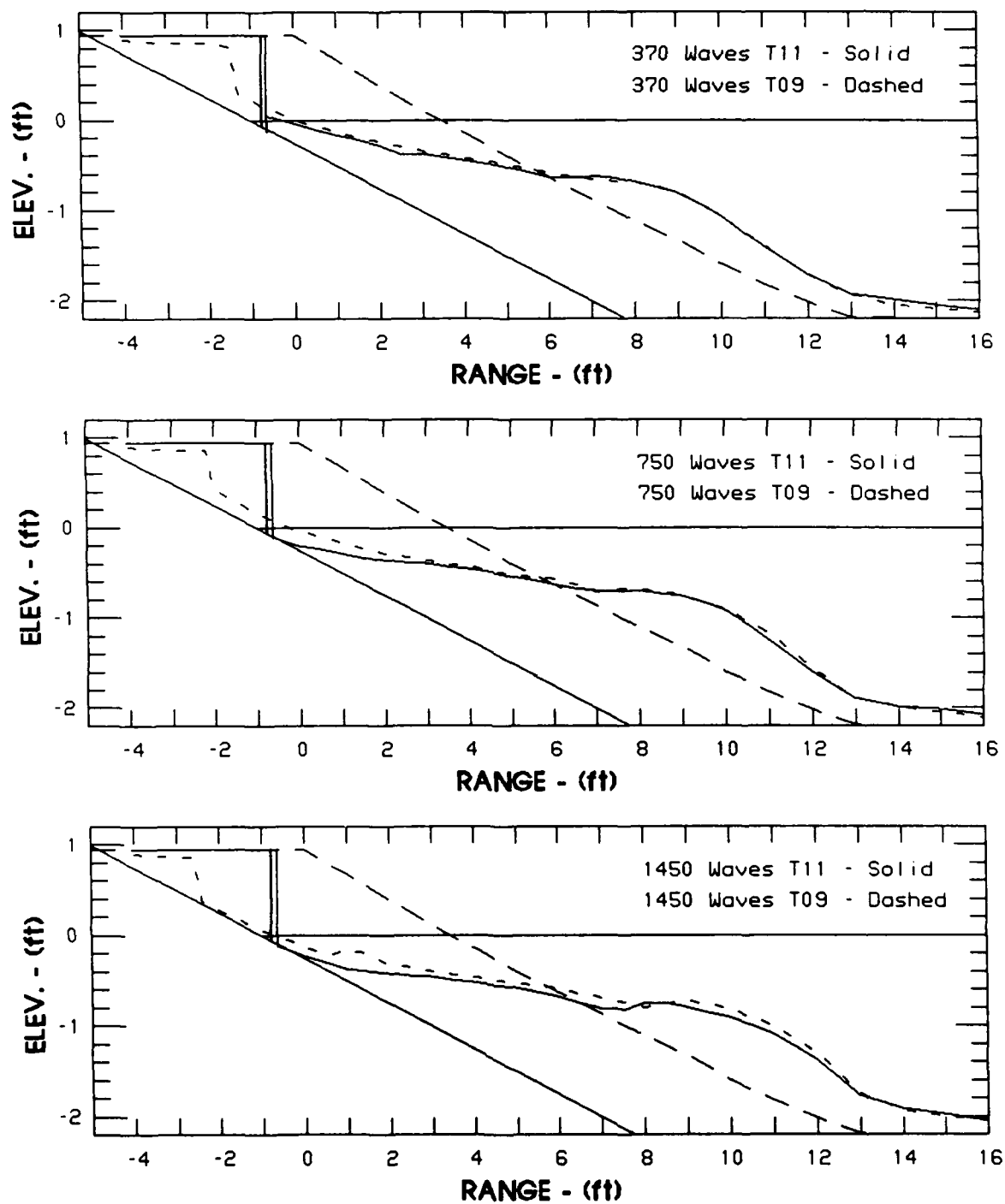


Figure E20. (Sheet 2 of 3)



## SEAWALL IMPACT - IRREGULAR WAVES

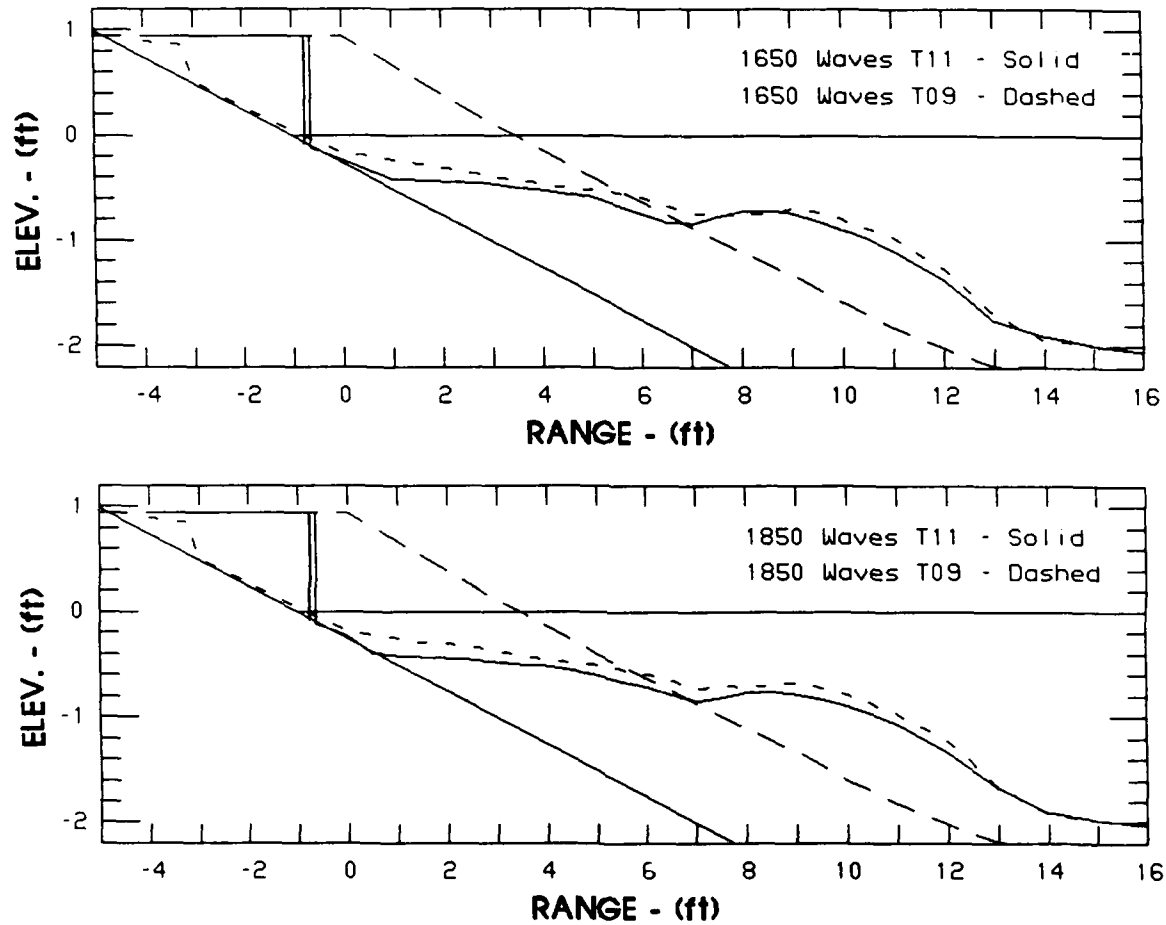


Figure E20. (Sheet 3 of 3)

# SEAWALL - IRREGULAR $H_{1/3}$ - $H_{mono}$

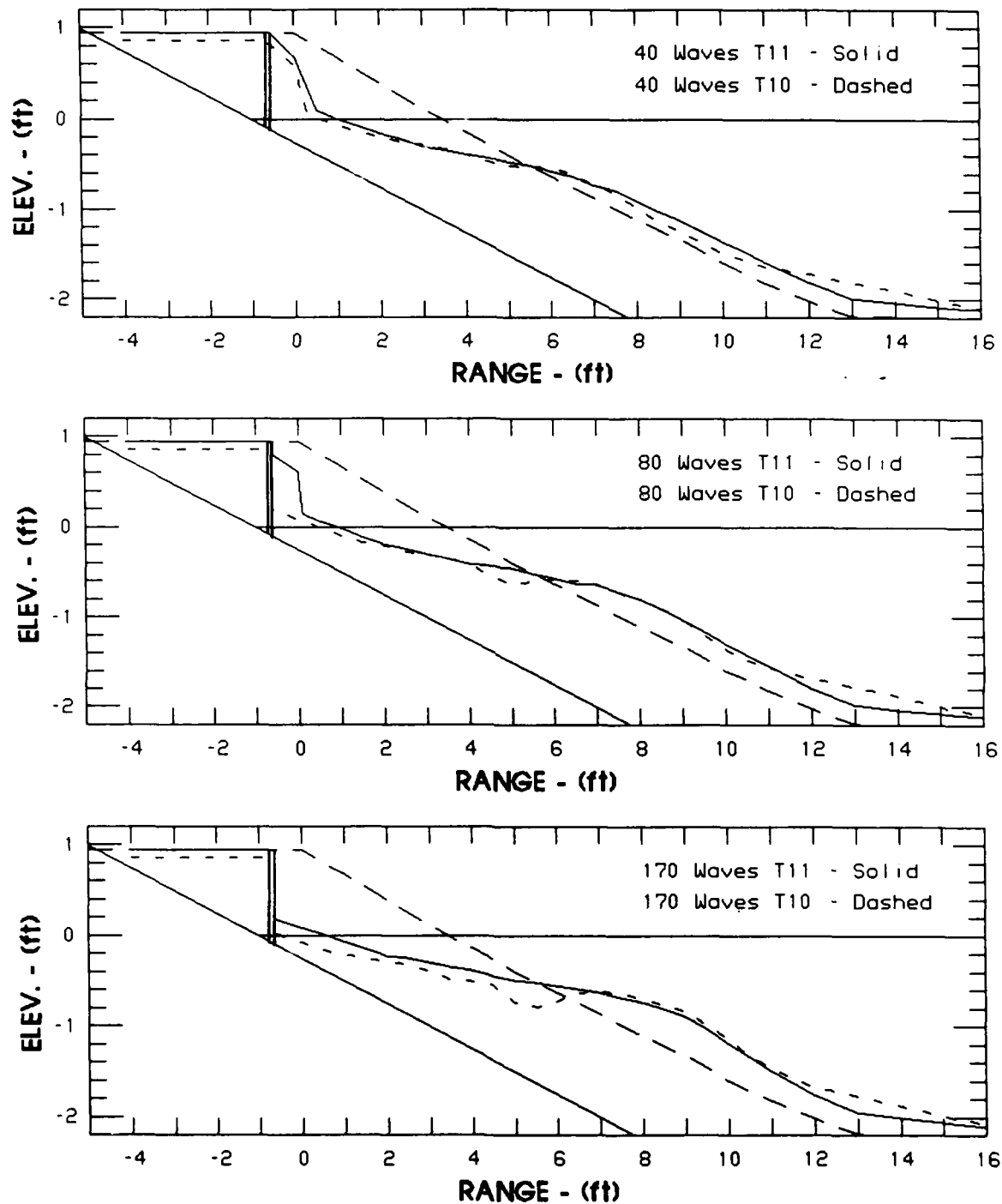


Figure E21. Seawall irregular wave comparison,  $H_{1/3}$  equals  $H_{mono}$   
(Sheet 1 of 3)

## SEAWALL - IRREGULAR H1/3 - Hmono

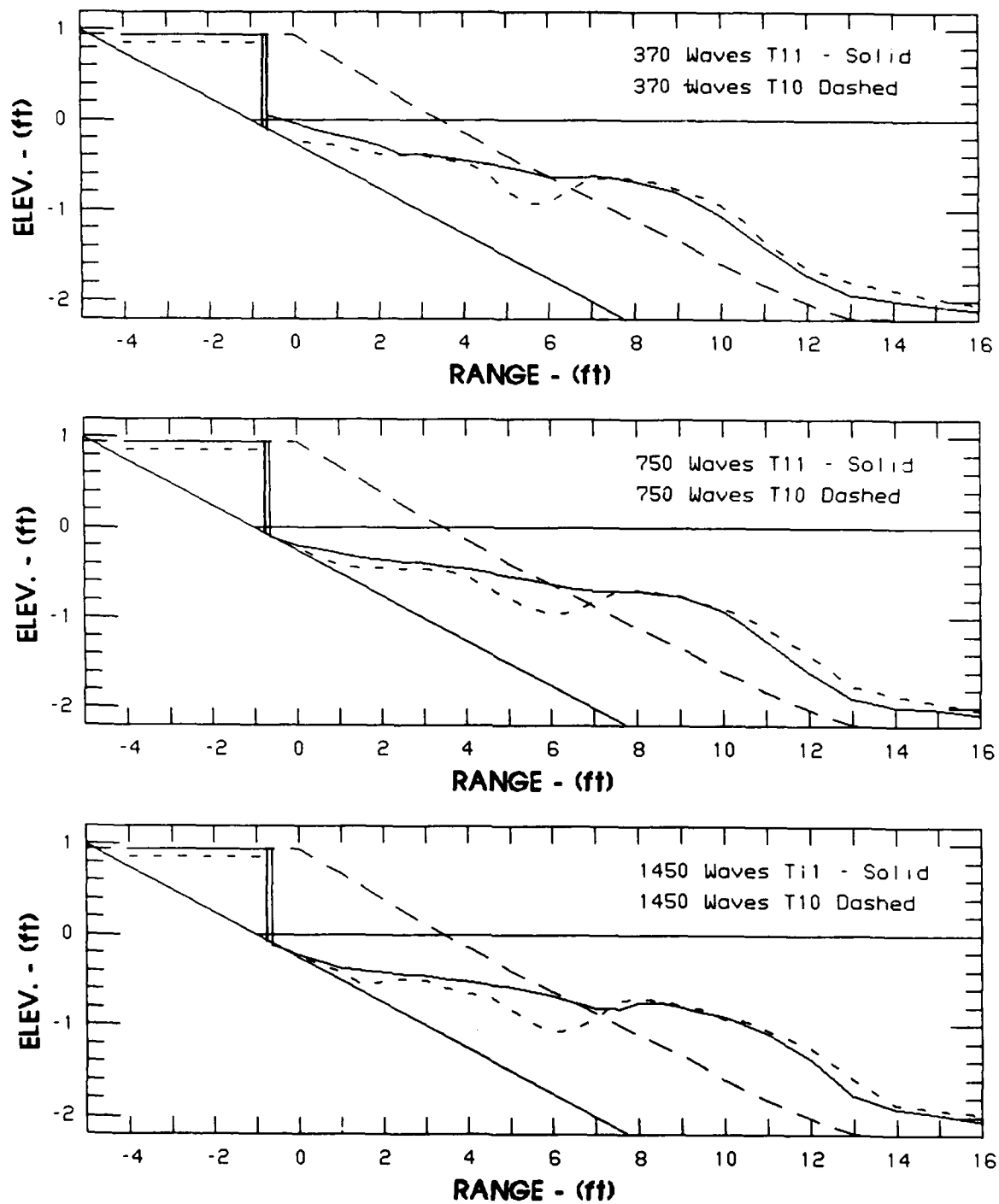


Figure E21. (Sheet 2 of 3)

## SEAWALL - IRREGULAR H1/3 - Hmono

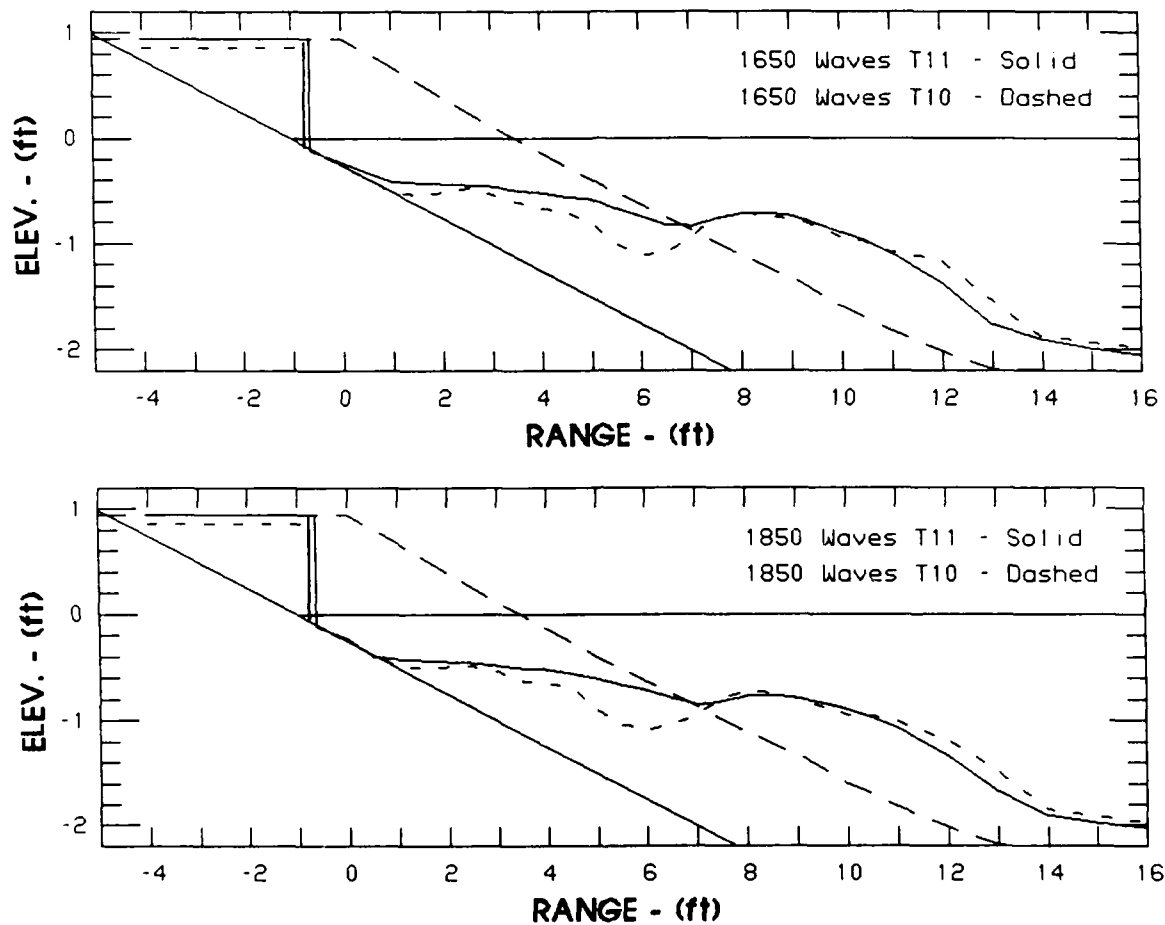


Figure E21. (Sheet 3 of 3)

## APPENDIX F: NOTATION

$C$	Profile along concrete sidewall of 6-ft flume
$d$	Sediment mean grain size diameter
$d_{50}$	Median grain size
$g$	Gravitational acceleration
$G$	Profiles along glass sidewall of 6-ft flume
$h$	Water depth
$h_m$	Model profile elevation
$h_p$	Prototype profile elevation
$H$	Wave height
$H_{mo}$	Primary energy-based wave height
$H_{mono}$	Monochromatic wave height
$H_o$	Deepwater wave height
$H_{rms}$	Root-mean-square wave height
$H_{1/3}$	Significant wave height equal to average of the highest one-third irregular waves
$H/L$	Wave steepness
$H_o/L_o$	Deepwater wave steepness
$K_r$	Reflection coefficient
$L$	Local wavelength
$L_o$	Deepwater wavelength
$m$	Subscript representing model
$N$	Prototype-to-model ratio of the subscripted parameter
$N_g$	Gravity scale
$N_l$	Length scale
$N_t$	Time scale
$N_w$	Fall speed scale
$N_*$	Scale based on horizontal velocities
$p$	Subscript representing prototype
$P$	Center-line profile
$t$	Time
$T$	Wave period
$U_{max}$	Maximum orbital water particle velocity near the bed
$U_*$	Critical velocity for incipient motion of the sediment
$w$	Fall speed of median grain sediment size
$\gamma$	Spectral width parameter
$\gamma'$	Immersed specific weight of sediment